PHD

Design transaction monitoring: understanding design reviews for extended knowledge capture

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Award date:
2006

Awarding institution:
University of Bath

Link to publication

DESIGN TRANSACTION MONITORING:
UNDERSTANDING DESIGN REVIEWS FOR EXTENDED KNOWLEDGE CAPTURE

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A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Mechanical Engineering

September 2006

[The viva voce examination was held 14th September 2006 at the Massachusetts Institute of Technology, Boston, USA. The members of the jury were: Professor Warren Seering (external examiner, MIT), Professor Neil Allan (internal examiner, University of Bath), Professor Stephen Culley (academic supervisor, University of Bath), and Professor Clément Fortin (academic supervisor, École Polytechnique de Montréal).]

"Because in the end we forget everything, anyway. We're human; we're amnesia machines."

– Douglas Coupland

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ACKNOWLEDGEMENTS

I would first like to thank my "team" of academic supervisors: Professors Steve Culley, Chris McMahon, and Clément Fortin. I am forever grateful for the trust and understanding you manifested all along my rather unorthodox research path which finally lead to the completion of this thesis.

The viva voce examination held at the Massachusetts Institute of Technology proved to be a stimulating and ultimately rewarding experience. I would therefore like to thank Professors Warren Seering (the external examiner from MIT) and Neil Allan (the internal examiner) for their enthusiasm regarding my work and the recommendations they made to improve the content of this document.

I would also like to thank Florence Sellini and her colleagues from the Airbus UK Knowledge Management team for their precious comments and help regarding the industrial relevance of my work. At the same time, I want to acknowledge the engineers who readily accepted to be monitored during design reviews in the context of this research.

I must thank the whole CAMAQ project team for their friendship, eager participation, and general open mindedness towards the monitoring environment and research tools I tested during their design reviews. For this specific case study, I also want to acknowledge the industrial supervisors (Jim, Normand, Rémy, Richard, and Warren) and the Centre for Aerospace Manpower Activities in Quebec (CAMAQ) for letting me participate in this unique design project, for leaving me *carte blanche* to videotape all the design reviews, and for helping me distribute the "meeting minutes" questionnaire to aerospace companies in the Montreal area.

I would like to acknowledge the EPSRC and Airbus UK for funding the research reported in this thesis (case study grant N°02300702). I am also grateful to the Innovative Manufacturing Research Centre (IMRC) at the University of Bath and the Mechanical Engineering department at École Polytechnique de Montréal for providing an ideal research environment to carry out my work.

I would like to thank my family, friends, and colleagues at the IMRC for their constant and unconditional support.

Marie, without you none of this would have ever happened ... thank you ∵ !

ABSTRACT

Engineering design reviews are fundamental elements of an evaluation and control process and take place at various stages of the product development process. However, most companies also acknowledge that these meetings are opportunities for all the parties involved to share information about the product and related engineering processes. For product development teams, the knowledge transfer processes that take place during a design review are not as secondary as they may seem; key design decisions, design experiences and associated rationale are made explicit.

Useful work has been carried out on the design review process, but little has been said about the detail of the activity itself. Understanding the mechanisms of a meeting and its working environment is critical to building an effective knowledge-oriented recording strategy. To this effect, an extensive research programme based on case studies in the aerospace engineering domain has been carried out. The study of the literature has generated a unifying description of the constitutive elements of design meetings in general, along with a generic model of the information processes that occur during design reviews. The work reported in this thesis then focuses on a set of tools and methods developed to characterise and analyse in depth the transactions observed during the case studies, referred to as the Design Transaction Monitoring (DTM) case studies. The first methodology developed – the Transcript Coding Scheme – uses an intelligent segmentation of meeting discourse transcriptions. To bypass the time consuming transcribing operation, a different approach was also adopted whereby a meeting observer uses a specially designed Meeting Capture Template to record the important information elements as the meeting takes place. The interpretation of the results in terms of decisions, actions, rationale, and lessons learnt is based on a third methodology: the Information Mapping Technique.

Further investigations into minute taking practices in the aerospace industry, based on a study of examples of design review minutes and a survey to evaluate their role in engineering activities, clearly indicate that meeting minutes must be "action driven" in order to be productive. The author has therefore elaborated an action-oriented strategy to improve the capture of key knowledge elements from design reviews. This strategy and the set of analytical tools presented in this dissertation have fostered practical guidelines, templates, and conceptual software requirements for the knowledge intensive capture of design review contents.

LIST OF ABBREVIATIONS

2D	Two Dimensions
3D	Three Dimensions
BOM	Bill Of Material
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CAMAQ	Centre for Aerospace Manpower Activities in Quebec
CAPP	Computer Aided Process Planning
CDR	Critical Design Review
CE	Concurrent Engineering
CORMA	practical methods and tools for corporate knowledge management
CR	Concept Review
CRM	Customer Relationship Management
CSCW	Computer Supported Cooperative Work
DIAK	Design Information and Knowledge (research team, IMRC, UK)
DMU	Digital Mock-Up
DRCS	Design Rationale Capture System
DRL	Decision Representation Language
DTM	Design Transaction Monitoring
EBoK	Engineering Book of Knowledge
ERP	Enterprise Resource Planning
FBS	Function Behaviour Structure
FEM	Finite Element Modelling
GDSS	Group Decision Support Systems
GSS	Group Support Systems
IBIS	Issue Based Information System
ICARE	Illustrations, Constraints, Activities, Rules and Entities
ICSI	International Computer Science Institute (Berkeley University, USA)
IDEA	Information for Design Engineering in Aerospace (U. of Bristol, UK)
IDEF	Integrated Definition language
$IDEF_0$	Integrated Definition language for function modelling
IM	Instant Messaging
IMRC	Innovative Manufacturing Research Centre (University of Bath, UK)

IMT	Information Mapping Technique
IPPD	Integrated Product and Process Development
IPT	Integrated Product (or Process) Team
IT	Information Technology
KBPS	Knowledge-Based Problem Solving
KM	Knowledge Management
KMi	Knowledge Media institute (Open University, UK)
KOPE	Knowledge-Oriented Practices for Engineers
MCT	Meeting Capture Template
MD	Mini Disc
MOKA	Methodology for Knowledge Based Engineering Applications
PC	Personal Computer
PDA	Personal Digital Assistant
PDM	Product Data Management
PDR	Preliminary Design Review
PICK	Process Improvements based on Corporate Knowledge management
PLKM	Product Life-cycle Knowledge Management
PLM	Product Life-cycle Management
PPRE	Product, Process, Resources, and External factors
QOC	Questions, Options and Criteria
RR	Requirement Review
SCM	Supply Chain Management
TCS	Transcript Coding Scheme
UML	Unified Modelling Language
WAV	Waveform audio format

CHAPTER 1

INTRODUCTION

The Design Transaction Monitoring (DTM) project, the research reported in this thesis, focuses on a particular collaborative event: design reviews. These are key milestones in the design process of complex products such as aircrafts. The study of engineering design meetings in general spans many research topics but has never, in itself, drawn much attention in the design community. The purpose of this dissertation is not only to acquire an understanding of what happens during the event, but also to develop tools and methods to enable an extended knowledge-oriented capture of its contents for further reuse.

This introductory chapter will first sketch out the engineering work environment in which design reviews take place. Background information on product development processes and Concurrent Engineering practices will help the reader to picture the role and importance of a design review, the core activity of the design control process, in aerospace engineering projects. The subsequent sections will then detail the research approach adopted by the author to manage the various case studies and findings reported in this thesis.

1. BACKGROUND AND MOTIVATION

Large corporations are facing increased competition on the global market and their engineering departments have to constantly improve their work strategies to produce higher quality products in less time. Product development teams are therefore pushed to enhance their practices to match current industrial trends in terms of multidisciplinary involvement, integration of tools and processes, and worldwide distribution of partners and stakeholders. Nevertheless, according to a recent study (Olson *et al.* 2002), radical collocation where team members are working in a same room for the duration of the project is twice as productive as a situation where participants are merely working in nearby offices or even cubicles. Hence, to meet the implicit requirements imposed by "global" teamwork, meeting technologies, such as videoconferencing, have been developed to enable distributed teams to discuss issues in a "virtual" collocated mode. Meetings in the workplace have therefore multiplied in various forms over the years, but most stakeholders involved hold them in contempt (Little 2004). What is it that makes meetings so necessary but so frustrating at the same time? The study of face-to-face meetings spans many current research topics but has never, in itself, drawn much attention in the design community. It is during these events that information flows, decisions are made, and design rationale or intent is established. The storage and archiving of these transactions is increasingly important and has to be considered as a major issue in the improvement of information services for engineers.

From these preliminary observations, the development of a transaction monitoring methodology to assist in extracting and storing the essential knowledge from design meetings appears as a clear opportunity for the growth of a company's intellectual capital. The "Design Transaction Monitoring" (DTM) research project, presented in this dissertation, has focused on a specific type of meeting: the design review. This particular choice of meeting was not arbitrary; it relates to a true concern within the aerospace industry and particularly at Airbus UK – the industrial partner who co-funded this project – which implies that even these formal meetings regulated by standards and company guidelines are not exploited at their full potential in terms of company knowledge capitalization.

This research objective has led the author to conduct a series of case studies based on both academic and industrial projects in the field of aerospace design. The results of these studies ultimately show that minutes, the central document of formal records of meetings, are often limited in the extent to which they capture the information exchange that has taken place. New means are therefore needed to capture the essential design knowledge, experience and expertise shared; alternative solutions to current practices will be therefore proposed in the final chapters of this thesis. In the meanwhile, this introductory section will focus on a review of the work processes and practices used by engineering teams to develop complex products. Indeed, when carrying out a research case study on a specific category of professionals, in this case aerospace engineers, one of the first steps forward is to gain an understanding of their work methods (Waldron and Waldron 1996a). Here, the methodologies and practices which have drawn attention are therefore centered on the development of a complex product; design reviews are part of the design control process, one of the critical aspects of the product development process, used in the aerospace industry to verify the quality of the work achieved. Therefore, this section will first examine the product development process and its application in the aerospace industry before detailing its associated formal control process.

1.1. The product development process and its application in the aerospace industry

The scope of the engineering activities involved in the process of product development has been summarised by Ulrich and Eppinger (2000), who argue that:

> *"Product development is the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product."*

For the purpose of this thesis, the author defines product development as the different design, engineering, and manufacturing processes involved from the definition of the market needs to the end of the production ramp-up (the point in time when the satisfactory manufacturability of the product is reached). At the end of the production ramp-up, the product must have satisfied its cost, quality, and production throughput targets. The product development cycle therefore includes all activities up to the end of the production ramp-up including the product and the manufacturing process development tasks. Life-cycle processes or product life-cycle processes are the different procedures affecting the stages of the life of a product, from the initial idea to its disposal. From these definitions it now seems important to introduce two major perspectives of the product development process: formal design methodologies and Concurrent Engineering (CE) practices. A practical insight through their application in the aerospace industry will then be proposed.

1.1.1. Design methodologies

Many design studies have tried to model the design process from different perspectives and their subsequent classifications have been the topic of various research reviews (Finger and Dixon 1989, Blessing 1994, Wynn and Clarkson 2005). It is not in the intention of this thesis to go into the detail of design methodologies but rather to propose a summary of the numerous perspectives which can be encountered in the literature. Clarkson and Eckert (2005), for example, dedicate two entire chapters where complete illustrations and detailed analyses can be found. Table 1.1 is based on an interpretation of the various design model categories reported by Wynn and Clarkson (2005); it is a reference table which defines the categories used in figure 1.1.

Figure 1.1 is a description grid used to list and categorise some of the design models. The table and the grid summarise the work presented in Wynn and Clarkson (2005) and O'Donovan *et al.* (2005), and can be used as a comparative guide of design methodologies. Most of the examples used in the grid are also referenced in Wynn and Clarkson (2005), although some have been added by the author (e.g. axiomatic design, 3rd Generation process) to verify the validity and completeness of the categorisation proposed in table 1.1.

Figure 1.1 shows that design methodologies have been developed for different areas of the product development process: the product development as a whole, the design, the verification/validation and control, the product life-cycle environment, or the planning and process improvement. Each row in the grid (figure 1.1) is a design model and is referred to by: its name or the author's name by default, references so that the reader can go to relevant sources for more detail, and a description is given using check-boxes to relate the appropriate categories (in table 1.1) which best define the model. A different type of check-box symbol has been used to distinguish categories and sub-categories (in the case of procedural approaches). Overall, a distinction needs to be made between the models which are descriptive and those with the intent of improving current processes. Informative models focus on different aspects of the engineering business (the design, the product development, the product life-cycle environment, the validation/verification and control), and provide the stakeholders, who are not actively participating in the engineering aspects of the project, with a generic view of the engineering context. But most researchers are in agreement and say that these models are too generic to offer real solutions to practical design process issues (Wynn and Clarkson 2005) and fail to propose a unified vision of the design process (Waldron and Waldron 1996b).

Table 1.1 *Design model categories*

Category	Definition
Stage-based	Refers to models with a decomposition of the product life-cycle into phases or stages. Purely stage based models are linear and sequential in nature and the possibility of rework is shown by using feedback loops in the process. Combined stage-based and activity-based models also exist.
Activity-based	Refers to models which focus on the iterative problem-solving nature of design activities. They typically characterise design as a cyclical and rework intensive activity gradually converging to the design solution. Combined stage-based and activity-based models also exist.
Solution-oriented	Models which look at the strategy adopted to reach the design goal. Here, solution-orientated strategies take the view that once an initial solution is outlined it is continuously refined and modified to match the design space and requirements. Activity-based models can be solution-orientated in nature.
Problem-oriented	Models which look at the strategy adopted to reach the design goal. Here, problem-orientated strategies emphasise on abstraction and call for the structuring of the problem before proposing a set of solutions. Stage-based models usually infer problem orientated strategies. Some activity-based strategies can also be problem orientated in nature.
Abstract approach	These models provide high level and generic descriptions of the design practice. They only include a small number of stages or activities and do not propose techniques to reach the design solution. Abstract approaches are usually *descriptive* in nature.
Procedural approach	Procedural approaches prioritise descriptions of specific aspects of product development and are more practical in nature than abstract approaches. They typically include a large number of phases and aim at a specific area of the product development process.
Descriptive	These procedural approaches are based on the observation of engineers' work across the development process of a product. They ground their theory on studies of actual engineering practices.
Prescriptive	These procedural approaches try to outline best practices to improve the effectiveness, efficiency and performance in certain aspects of the product development project.
Models	These *"refer to a description or prescription of the morphological form of the design process"* (Wynn and Clarkson 2004).
Methods	These *"prescribe systematic procedures to support the stages within a model"* (Wynn and Clarkson 2004). Models and methods approaches are often intertwined in the proposed modelling schemes.
Design-focused	This category is centred on the technicalities of solving design problems. They take a product focused perspective and do not acknowledge the complexity which lies in the integration of methods, tools, people and domains.
Project-focused	This category takes into account the whole product development process. Within this category views have focussed on different aspects of the product development process, such as integration of personnel and disciplines, consideration of manufacturing constraints, verification/validation and control, external influences on a project etc.
Analytical approach	These approaches describe very specific aspects of product development activities and processes. They often use techniques or computer tools to visualise detailed representations which aim at improving the process and its related performances.

Source: adapted from Wynn and Clarkson (2005).

Emphasis of the modelling	Author or model name	Reference(s)	Stage-based	Activity-based	Problem-oriented	Solution-oriented	Abstract approaches	Procedural approaches	Model	Method	Project-focused	Design-focused	Prescriptive	Descriptive	Analytical approaches
Design	Pahl and Beitz	Pahl and Beitz (1984)	●		●			●	○	○		○	○		
	Hubka	Hubka (1982)	●	●	●			●	○	○		○	○		
	The design spiral	Evans (1959)		●		■		●	○			○	○		
	French	French (1999)	●		●			●	○	○		○		○	
	Product model or Chromosome	Andreasen (1992)		●	●			●	○	○		○	○		
	Pugh	Pugh (1991)	●		●			●	○	○		○	○		
	Darke	Darke (1979)	●		●		●								
	PDI model	March (1984)		●		●	■								
	Jones	Jones (1963)	●		●		■								
	Axiomatic design	Suh (1990)		●		●	●								
	Cross	Cross (1994)	●		●	●	■								
Product development	Integrated Product Development	Andreasen and Hein (1987)	●		●			●	○		○		○		
	Ulrich and Eppinger	Ulrich and Eppinger (2000)	●		●			●	○	○	○		○		
	Ullman	Ullman (1988)	●		●			●	○	○		○		○	
	Waldron	Waldron *et al.* (1989)		●	●	●		●	○	○	○			○	
Verification, validation and control	Waterfall model	FDA (1997)	●		●			●	○		○			○	
	Medical device V-Model	Alexander and Clarkson (2000)	●		●			●	○		○			○	
	Stage-gate process	Cooper (1993)	●		●			●	○	○	○		○		
	3rd Generation process	Cooper (1994)	●		●			●	○		○		○		
Product life-cycle environment	Total product life-cycle	FDA (2001)		●		●		●	○		○		○		
	Hales	Hales (2004)		■		●		●	○	○	○		○		
Planning, process improvement and quality	PERT	PMI Standards Committee (2000)		●			●								●
	CPM	PMI Standards Committee (2000)		●			●								●
	IDEF	NIST (1993); Mayer *et al.* (1995)		●		●									●
	QFD	Mizuno and Akao (1994)		●		■									●
	DSM	Eppinger *et al.* (1994)		●		■									●
	Signposting	Clarkson and Hamilton (2000)		●			●								●
	Petri nets	Peterson (1981)		●		■									●
	GDM	Van Langden (2002)		●			●								●
	MILOS	Dellen and Maurer (1996)		●		●									●
	UML	Booch *et al.* (1998)		●		●									●
	MDO	AIAA (1991)		●			●								●

Description using typical categorisations of design models

***Figure 1.1** Examples of design models and their description using typical categorisation schemes based on Wynn and Clarkson (2005) and O'Donovan et al. (2005)*

Current industrial standards, such as the BS7000-2 (1997), propose guidelines for the management of the design of manufactured products based on a stage-based decomposition of the design process inspired by some of the theoretical models presented in figure 1.1 which emphasise on the product development process.

Of course, even these standards acknowledge the fact that the proposed models (design and product development models in figure 1.1) have a limited use for designers themselves, but are a necessary framework to manage the project and provide a sufficiently detailed view of the process so that all stakeholders know where they stand:

"An organization's standards of design are affected far more by those who manage design than by the specialists who undertake the creative work. (...) It is the board's collective responsibility to ensure that the organization has an understanding and a clear stance and sense of direction with respect to design so that all contributors and disciplines may be harnessed to their full potential." (BS7000-2, §2.2, 1997)

1.1.2. Concurrent Engineering practices

The previous section has described various models for the product development process. Nevertheless, these do not say much about how the development of a product should be managed or where and when the different methodologies can be applied.

The comparative studies on the introduction of new products in Japan and in the West published by Womack *et al.* (1990) and Clark and Fujimoto (1991) have inspired the definition of the essential drivers for a successful management of the product development process: reduction of the "time to market", improvement of the overall quality of product and processes, and reduction of product and process development costs (Berndes and Stanke 1996). To achieve these goals, companies seek effectiveness and efficiency (do the right things, do them right and at the right time) where time, costs, and quality are the key factors (Berndes and Stanke 1996; Brookes and Backhouse 1996). The strategy to address these competitive aspirations is now known as Concurrent Engineering (CE) or simultaneous engineering (Evans 1988) as it was called in the early years of its definition. In 1987, the US Defence Advanced Research Projects Agency (DARPA) studied the implications of simultaneous engineering, which essentially looked at jointly designing the product and its process (Wesley Allen 1990), and extended the definition to:

"Concurrent engineering is a systematic approach to the integrated concurrent design of products and related processes including manufacturing and support. This approach is intended to cause the developers from the outset to consider all elements of the product life-cycle from conception through disposal including quality, cost, schedule and other user requirements." (Winner et al. 1988)

In practice, CE targets strategic interactions between time, costs, and quality through a parallelisation of processes and tasks, an integration of departments, persons, and tools, and a standardisation of the product development process (Berndes and Stanke 1996).

The concept of parallelisation of tasks and processes can be visualized with the diagram presented in figure 1.2, which is based on a simple decomposition of the product development process and six random engineering tasks.

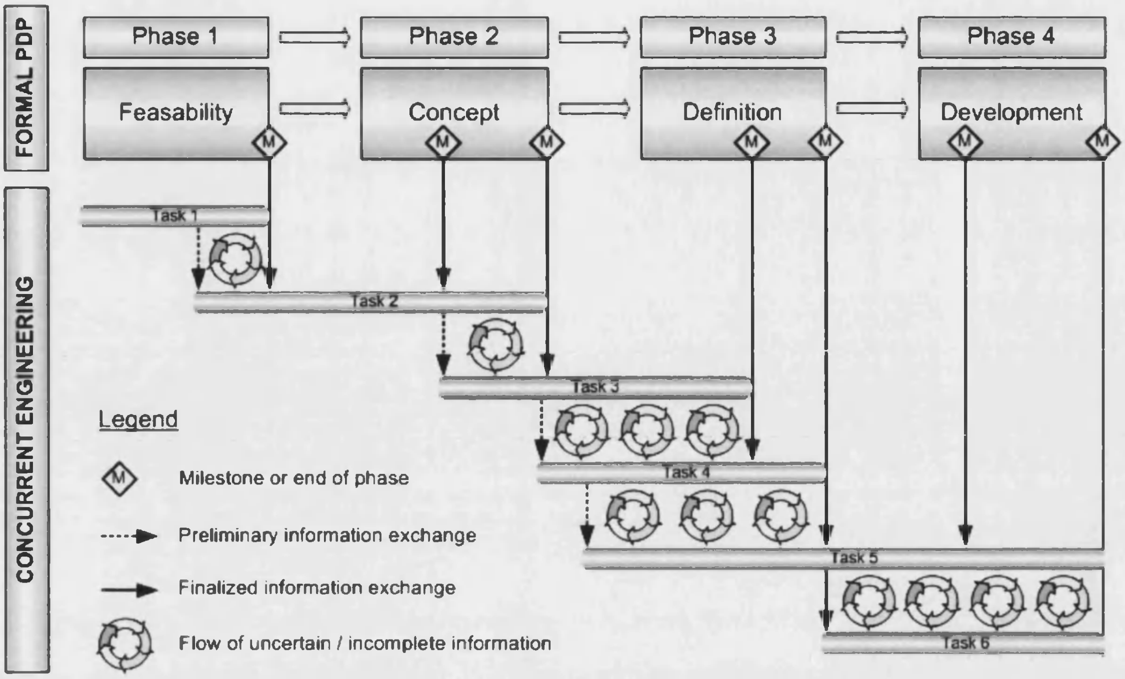


Figure 1.2 *Parallelisation mechanisms in Concurrent Engineering and their impact on the information flow relative to a formal Product Development Process decomposition*

Figure 1.2 outlines the importance of the information flowing between tasks or processes and the control mechanisms, in this case formalised by milestones, which ensure the validity and quality of the information being transferred and keep track of the planning of the project. The finalized information exchange flows are typically embodied in what engineers call "deliverables". The critical point suggested in the diagram is the management of the uncertain or incomplete information flow which occurs between the preliminary information and the finalised information exchanges (Krishnan *et al.* 1997). Interestingly, Eversheim and Shulten (1999) propose the notion of optimal degree of parallelism and integration between the design and process planning tasks and outline its key influential factors: resistance to change, product complexity, involved disciplines, innovation level, information interdependencies, etc.

Standardisation is also one of the main objectives of CE. Standardisation can occur for both the product and its development processes. Standard product development processes will be sought when faced with certain routine activities which can be completely specified and generalised (Berndes and Stanke 1996). Standard systems and components will also help to reduce costs and provide product stability (Berndes and Stanke 1996). Finally, standardisation is also related to software, technical procedures, and formal communication between projects and departments. Berndes and Stanke (1996) argue that:

> *"The objectives of standardisation are to avoid repetition and needless work as well as to learn from existing experiences of the company. Thus, repetitive and similar decisions will be taken off the staff on the one hand and on the other hand a better coordination will be achieved."*

The integration dimension of CE is probably the most difficult aspect to achieve for any enterprise. Integrated Product and Process Development (IPPD) is the response to the complexity of implementing CE, providing a framework for the simultaneous design, engineering, manufacturing, and support of a product. One of the central elements of IPPD is the team and is therefore sometimes referred to as Integrated Product (or Process) Team (IPT). An IPT can be organised in different ways according to the work environment provided by the company. Various multidisciplinary team structures have been detailed in engineering research literature (Backhouse and Brookes 1996, Smith 1997, Schmidt *et al.* 2002). Concurrent Engineering does not always imply a radical change in team structure; one of the results from the study carried out by Clark and Fujimoto (1991) is that communication centred on the efficient use of preliminary information rather than complete information (see figure 1.2) is paramount to good team integration.

To support teams in their quest to enhance efficiency in temporally and physically distributed situations, a number of advanced information technologies have been developed. With the knowledge and experience of CE gained over the past two decades (since it has officially been defined and formalised), it clearly appears that the engineering tools used by members of an IPT need to be properly integrated along three generic axes of integration: the concept to product axis, the engineering to production axis, and the supplier to client axis (Fortin and Huet 2007).

The concept to product axis represents the activities required to develop a single product. This dimension focuses on the spatial and physical embodiment of the product. The physical characteristics such as the dimensions, the tolerances, the surface finish, and the performance of the product are the main variables which must be defined and fully implemented in the final product.

The engineering to production axis discloses internal company processes within a product development team and organization, where product development processes are at the heart of the problem. Engineering to production processes are responsible for the management of the product and process data across disciplines and along the whole product life-cycle.

The supplier to client axis deals with external company processes. The goal is to manage the extended business, from the selection of a supplier (or partner) to the sale of the product to the customers.

Figure 1.3 places major CE tools, used in the development of complex products, along the three axes of integration detailed previously. For an engineer taking part in a "virtual team" (Baird *et al.* 2000), the digital environment will usually involve computer aids dedicated to specific engineering tasks (e.g. CAD, CAM, CAPP, FEM, etc.). The generated data is then organised and shared using sophisticated data management technologies, shown in figure 1.3: Product Data Management (PDM), Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and Customer Relationship Management (CRM) software.

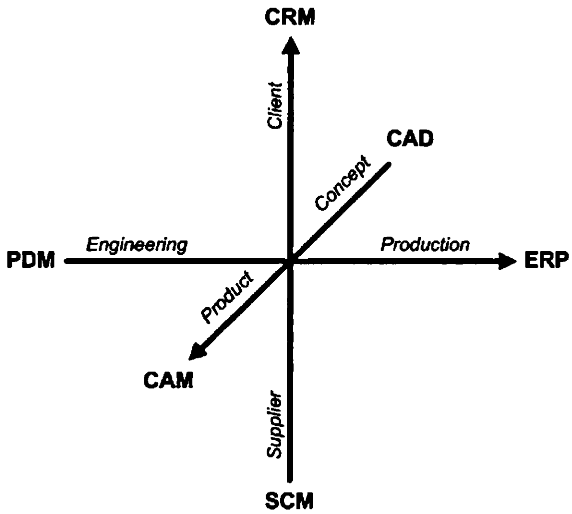


Figure 1.3 *Integration of major engineering data management tools (Fortin and Huet 2007)*

CE may have been formalized and defined only around the late 1980s, but it remains essentially an empirical approach for a strategic improvement of product development processes based on practices that have been around for a far greater lapse of time. There is not one single solution to implement CE in a company, but awareness of the issues and benefits is essential to make the right decisions.

1.1.3. A practical example: the product development process model at Airbus

Aerospace engineers, the category of professionals under study in the DTM research project, produce one of the most complex systems man kind has ever designed in the mechanical engineering field. An Aircraft is complex in many ways: it is composed of a multitude of parts, it requires input from many engineering domains, and the aerospace industry needs to employ a high number of engineering experts to finally develop a small range of aircrafts. This complexity is reflected in the overall design process for the development of a new aircraft, shown in figure 1.4. Here, the company has divided its activities in four main phases: the feasibility phase, the concept phase, the definition phase, and the development phase. These tend to match theoretical views on design methodologies presented previously in §1.1.1, but this sequential representation chosen by the company does not account for the important collaborative engineering processes embodied in CE practices outlined in §1.1.2.

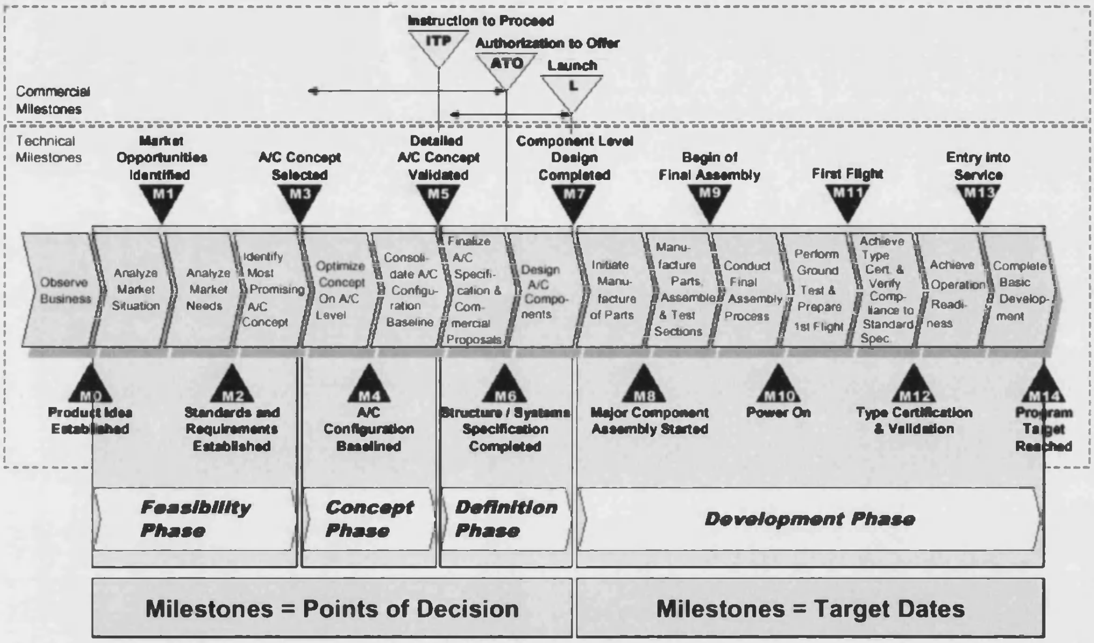


Figure 1.4 *The development process for a new aircraft at Airbus. Source: Airbus UK.*

Figure 1.5, which illustrates the product development process model proposed by Ulrich and Eppinger (2000), introduces another dimension to the decomposition in phases, i.e. the key functions of the organisation across the stages. The implicit interest of the matrix presented in figure 1.5 is the underlying need for an efficient coordination of these functions and phases using engineering management methods and tools, such as CE and IPPD. The variation in the decomposition into phases between figures 1.4 and 1.5 further illustrates the theoretical nature of design methodologies presented in §1.1.1. Both these perspectives are valid, but they focus on different yet complementary aspects of the product development process; figure 1.4 emphasises the major decision points and target dates, while figure 1.5 details the main tasks for each generic function involved in the development of the product (i.e. design, manufacturing, marketing, and other).

PHASES OF THE GENERIC PRODUCT DEVELOPMENT PROCESS

KEY FUNCTIONS OF THE ORGANIZATION	Planning	Concept Development	System Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing	• Articulate market opportunity • Define market segments	• Collect customer needs • Identify lead users • Identify competitive products	• Develop plan for product options and extended product family	• Develop marketing plan	• Develop promotion and launch materials • Facilitate field testing	• Place early production with key customers
Design	• Consider product platform and architecture • Assess new technologies	• Investigate feasibility of product concepts • Develop industrial design concepts • Build and test experimental prototypes	• Generate alternative product architectures • Define major sub-systems and interfaces • Refine industrial design	• Define part geometry • Choose materials • Assign tolerances • Complete industrial design control documentation	• Reliability testing • Life testing • Performance testing • Obtain regulatory approvals • Implement design changes	• Evaluate early production output
Manufacturing	• Identify production constraints • Set supply chain strategy	• Estimate manufacturing cost • Assess production capability	• Identify suppliers for key components • Perform make-buy analysis • Define final assembly scheme	• Define piece-part production processes • Design tooling • Design quality assurance processes • Begin procurement of long-lead tooling	• Facilitate supplier ramp-up • Refine fabrication and assembly processes • Train work force • Refine quality assurance processes	• Begin operation of entire production system
Other functions	• Research: demonstrate available technologies • Finance: provide planning goals • General management: allocate project resources	• Finance: facilitate economic analysis • Legal: investigate patent issues	• Finance: facilitate make-buy analysis • Service: identify service issues		• Sales: develop sales plan	

Figure 1.5 *Tasks and responsibilities for key functions of the organisation in each phase of the product development process (Ulrich and Eppinger 2000)*

The diagram in figure 1.4 highlights the importance of milestones, known as design reviews during the product development phases of the project, and acknowledges them as major decision points for the validation of the proposed solution and the coordination of the engineering tasks and activities detailed in figure 1.5. The next section will therefore focus on design reviews, the formal design monitoring technique used in the aircraft industry.

1.2. The control process for product development activities

As detailed previously, CE is a product development strategy based on empirical findings where structure, process, control, people, and tools drive its implementation (Backhouse and Brookes 1996). Although different approaches can be taken, there are aspects that remain similar from one experience to another, the control processes for instance. Review meetings in the product development process are usually adopted as one of the major project monitoring and planning techniques in industry.

1.2.1. The Stage-Gate process

In the aerospace industry, the "milestone process" or "Phased Review Process", illustrated previously in figure 1.4, is the norm to monitor the design process and validate design achievements. Design reviews, from a business point of view, can be seen as "Stage-Gates". This recalls the Stage-Gate process defined by Cooper (1993), where a gate is a decision point which divides the product development process in discrete stages. A generic Stage-Gate process is illustrated in figure 1.6.

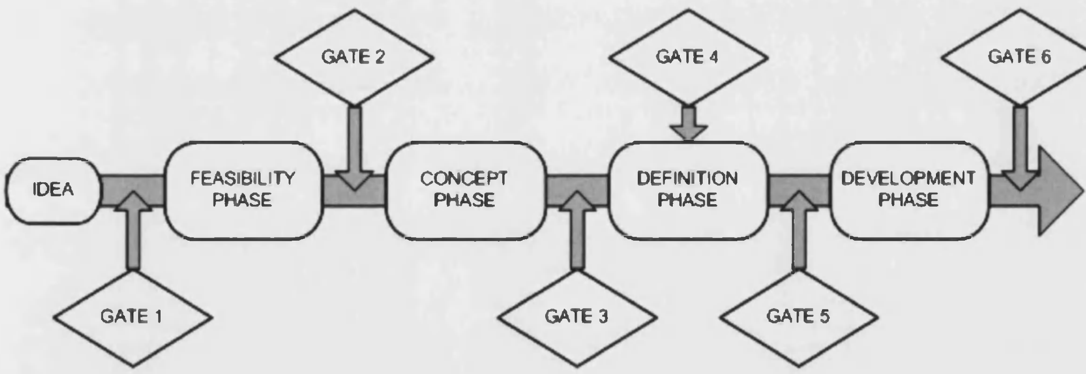


Figure 1.6 *A generic representation of the Stage-Gate process (Cooper 1993) applied to the aircraft development phases used at Airbus.*

Since the implementation of such management strategies based on a stage based decomposition of the design process, companies have further expanded the Stage-Gate process by inserting milestones or gates within their product development phases to increase the project monitoring needs of CE strategies (i.e. Gate 4 in figure 1.6). The objective of this technique is to bring the risk associated with the product development down to a minimum. Cooper (1993) defines a gate as a *"Go/Kill"* decision point:

> *"Gates are predefined and specify a set of deliverables, a list of criteria, both must meet (which are mandatory) and should meet (which capture desirable characteristics), and an output (for example, a decision and approved path forward)."*

Of course, the number of gates varies from one company to another. Phillips *et al.* (1999) carried out a study with six different companies, which had adopted a formal product development process divided into a number of phases ranging from four to ten. According to the findings and analyses proposed, a higher number of gates in the design and development stages improves the framework to review product cost and performance. Of course, too many reviews can quickly become nauseous for the project team and there is therefore a need to balance and optimise the control process by operating with more cross-functional teams, involving a wider variety of stakeholders over the life of a project (Phillips *et al.* 1999).

1.2.2. Formal design reviews

Design reviews or gates held during the design phases of the product development are formal meetings attended by a majority of the stakeholders involved in the project. These meetings are highly structured and follow precise company guidelines imposed by the international standard IEC 1160:1992 (1992) and adopted by national standards institutions (BS 5760-14: 1993; CSA 1160-96:1996). To illustrate the formality of these meetings, here is the definition of a design review taken from the International Electrotechnical Commission (IEC 1160: 1992 cited BS 5760-14: 1993):

> *"3.1 (Formal) design review: a formal and independent examination of an existing or proposed design for the purpose of detection and remedy of deficiencies in the requirements and design which could affect such things as reliability performance, maintainability performance, maintenance support performance requirements, fitness for the purpose and the identification of potential improvements."*

Overall, the standard provides a detailed framework for companies to plan, conduct, and implement formal design reviews. The general objectives of design reviews suggest that this formal event in the control process helps to reduce the time for a stabilised design, accelerates the maturing of the product and associated processes, and stimulates early product improvements. During reviews, corrective actions and recommendations must be made explicit and documented to *"permit continuity and follow-up until design decisions have been completed"* (IEC 1160:1992 cited BS 5760-14). Specific objectives of design reviews according to their position relative to the product life-cycle phases are reflected by their type. The international standard suggests the following types of design reviews to be held during the life of a product (see table 1.2). Of course, in practice, companies have often decided to multiply these reviews in a bid to improve their control process and have consequently named them slightly differently. Throughout this thesis, names and acronyms of the types of design reviews typically used in the aerospace industry will be preferred to the ones presented in table 1.2. For example, in the aerospace product development phases presented in §1.1.3 where most design efforts are deployed (the concept phase and the definition phase), four typical design reviews would divide the design process shown in figure 1.6: a Requirement Review (RR e.g. Gate 2), a Concept Review (CR e.g. Gate 3), a Preliminary Design Review (PDR e.g. Gate 4) and a Critical Design Review (CDR e.g. Gate 5).

Table 1.2 *Types of formal design reviews*

Life-cycle phases	Type of design review	Acronym	Specific objectives (BS reference)
Concept and definition	Preliminary	PDR	BS 5760-14 § 6.3.1
Design and improvement	Detailed	DDR	BS 5760-14 § 6.3.2
	Final	FDR	BS 5760-14 § 6.3.3
Manufacturing and installation	Manufacturing	MDR	BS 5760-14 § 6.3.4
	Installation	IDR	BS 5760-14 § 6.3.5
Operation and Maintenance	Use	UDR	BS 5760-14 § 6.3.6
Disposal	Normally not applicable	N/A	N/A

Source: § 6.1, table 1, BS 5760-14: 1993 (1993).

1.2.3. Improving the Stage-Gate process

Looking back at the Stage-Gate process and its evolution since its early implementation as the Phased Review Process at NASA in the 1960s to the 2nd generation model detailed in §1.4.1, Cooper (1994) outlines the need for a major evolution of this model currently in use. The Stage-Gate has been widely successful over the years (Cooper and Kleinschmidt 1990) but still generates barriers to CE principles. Six major weaknesses have been identified: projects are put on hold if gates are not completely validated, overlapping tasks is more difficult around the gate, a strict adherence to the scheme can delay low-risk projects, the prioritisation of resource demanding projects is overlooked, and the bureaucracy and over-detailed procedures involved are counter productive (Cooper 1994).

The Third Generation model, illustrated in figure 1.7, aims to improve the efficiency in the process with a strategy spelled out as four Fs: Fluidity, Fuzzy gates, Focused and Flexible. The introduction of "fuzzy gates", which removes the need for absolute decision points and installs conditional and situational milestones instead, is an interesting aspect because it implicitly recognises the complex nature of information flows between engineering tasks described previously in §1.1.2. These new gates offer the project team the possibility to continue their work and the invalid tasks simultaneously. Of course, this only applies to certain activities in certain situations and new target dates must be fixed for the remaining tasks.

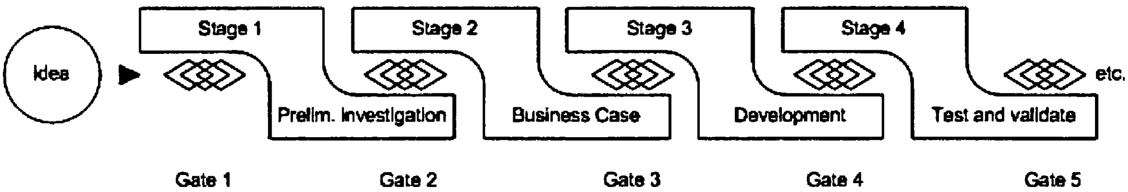


Figure 1.7 *The Third-Generation model (Cooper 1994)*

The new system presented in figure 1.7 advocates "flexibility, adaptability, conditionality and fluidity" (Cooper 1994), but the implementation of these concepts will not be a stroll in the park for managers. Added complexity will inevitably come from a shift in the decision making process, where team members will have more to say in order to add flexibility to the timing of the gates. The new process will also make it difficult for senior management to define precisely certain stages and they will have to rely on more incomplete information coming from the project team.

Although design reviews are primarily part of a control process, most companies also acknowledge the event as an opportunity for all involved parties to share information about the product and process. The creative input of a design review is now not as secondary as it may have been in the past. It is a place where key design decisions and their rationale are made explicit as will be explained in this thesis and has been externally published (Huet *et al.* 2006). With the new found influence of the project team during the event, the need to efficiently capture the information and knowledge circulated at a review is evidently a crucial step towards the success of a design guided by CE principles.

1.2.4. Design reviews: focus of the research

In practice, the core activity of the stage-gate process is a form of meeting where poor productivity and efficiency often frustrate its participants even when supported by new and glamorous information technologies (Little 2004). A lot of useful work has been carried out on the design review process, but little has been said about the activity itself.

Based on the literature reviewed so far in this chapter, aerospace design reviews can already be seen, from a research perspective, as collaborative activities with specific characteristics which set them apart from other types of meetings:

- They are guided by a number of formalised constraints (company guidelines and procedures, international standards, certification regulations, etc.).
- They follow a clear set of predefined objectives.
- As key events of the product development control process they are visible activities in business planning tools and documents across projects and companies.
- They provide a unique "information synchronization" point in the development of a product where the aircraft manufacturer and its suppliers can share information about the design and evaluate the progress.
- They represent a particular category of design meetings which are at the heart of the collaborative decision making cycle inherent to any product development process using a Stage-Gate control approach (Vliegen and van Mal 1990).

This thesis will look at understanding what goes on during these formal meetings based on industrial and academic case studies and propose a framework so that design reviews can efficiently support the market driven environment described in this chapter. The next chapter will therefore introduce in more detail essential aspects of knowledge, information and communication processes related to multidisciplinary product development teams. These will then be used in chapter 3 to further an understanding of the mechanisms of design transactions occurring during meetings. Although the topic of meetings has been studied in different research areas (social studies, linguistics, management science, etc.), the review literature discussed in chapter 3 will essentially focus on findings generated in the engineering domain in order provide a relevant framework for the study of engineering design meetings.

The next section will conclude this introductory chapter by describing the practical aspects of the research approach adopted by the author: the research methodology, the underlying research questions, and the detail of the research activities carried out during the past 4 years.

2. RESEARCH APPROACH

Research in the field of mechanical engineering design is generally focussed on studying the act of designing (Minneman 1991). This means the study of design processes and activities, but then the issue of how to approach design research inevitably comes to mind. Because of the empirical nature of the design research field, it is of up-most importance for researchers to be clear about their methodology and the context from which the results have been drawn. This section therefore provides a retrospective description of the research methodology employed by the author based on a brief categorisation of various research approaches used in the design research community. The main research questions that have guided the work presented here will also be outlined and a summary of the research activities carried out over the past four years in the form of a "research circuit" diagram will close this chapter.

2.1. Categorising design research approaches

In his thesis, Minneman (1991) goes into great detail on the topic of design research methods providing the community with a valuable reference for choosing an appropriate stand point on the matter. Three categories of research approaches to design process studies can be outlined: prescriptive, computational, and descriptive (Finger and Dixon 1989; Minneman 1991). Table 1.3 is the author's summary of this work and presents the major categories and sub-categories, a brief description, examples through key references, the main techniques employed in each case and the core limitations for each category. In essence, the table highlights the fact that there is no perfect approach; the best way forward is most probably to integrate a variety of research methods and to remain completely transparent about what has been used.

A few remarks concerning the techniques related to each category need to be made. Rational techniques, shape grammars, and morphological approaches are rationalistic approaches aiming at systemising the design process into a sequence of well defined tasks and activities (Minneman 1991). The use of such techniques derives from the will to develop a scientific theory to guide engineering design (e.g. Suh 1990).

Holistic approaches on the other hand are descriptive in nature, focussing on occurrences in design activities. Here techniques such as participatory design, where the end user is involved in the design activities, or protocol analysis which asks the designer to think aloud while he is accomplishing his tasks have been employed more or less successfully over the years. These techniques were initially intended to observe individuals rather than teams (Minneman 1991). In the design engineering research domain, many descriptive approaches blend in a slight prescriptive method in order to improve strategies, practices and the knowledge of the environment under study. These methodologies could be seen as "action research" from a social science point of view, where action research must be understood as a study of a group of professionals by researchers working in the same domain in order to improve its practices (Reason and Bradbury 2001).

Finally, interaction analysis, an action research type methodology, was brought in to void the gap for design group observation; the approach adopted in this research and presented in the next section has slightly adapted the interaction analysis technique to match the specific requirements related to the nature of the DTM case studies.

Table 1.3 Types of approaches to design research

Types and *sub-types*	Description	Examples	Techniques	Limitations
Prescriptive	Prescriptive research will define rules and methods and prescribe the designer to follow them. They tend to be efforts to try and formalise the design process.	Hubka (1982) Pahl and Beitz (1984) Pugh (1991)	Rational techniques	Relies on author's experience. Linear technique. No practical evaluation.
Computational	The research is focused on the role of computation in design. Two distinct approaches can be singled out: aid to design and design automation.	McMahon and Browne (1998)	Shape Grammars	Perception, intuition, experience and manual skills are often neglected.
Aid to design	Aid to design research aims at supporting designers with computer tools.	Faux and Pratt (1979)	Participatory design	Impact of the new skills required is not studied.
Design automation	Design automation attempts to automate specific design tasks.	Dyer *et al.*(1986)	Rational techniques	Underlying belief that design is a decomposable set of simple tasks.
Descriptive	Descriptive design research will observe and analyse design activities and try to interfere as little as possible with the ongoing work process.	French (1999) Waldron *et al.* (1989)	Holistic approaches	Finding the appropriate research method or technique.
Model observers	Approached derived from experimental psychology methodologies. The researcher identifies an interesting phenomenon, proposes hypotheses and verifies them through experimentation.	Newell and Simon (1972) Ullman (1988) Gero and McNeill (1998)	Protocol analysis	Design problem is simplified. Unnatural conditions. The team is a juxtaposition of individual designers
Naturalistic observers	Comparable to anthropological and ethnographical approaches. They aim at observing design practice *in situ*. The approach views design as social activity.	Bucciarelli (1988) Robins (1987) Hales (1987) Tang (1989)	Participatory design Interview techniques Retrospective methods Interaction analysis	Roles and norms are taken for granted. Observation can modify the natural setting.

Source: adapted from Minneman (1991).

2.2. The DTM research approach

Before detailing the research approach adopted by the author, it is crucial to outline the context of the work which will be reported in the rest of this thesis. Along the road that led to the completion of this dissertation, three monitoring case studies were carried out: design reviews held at Airbus UK, team meetings of undergraduate students working on a design project (University of Bath), and design reviews held during an aircraft pylon redesign project (Centre for Aerospace Manpower Activities in Quebec/CAMAQ project - École Polytechnique of Montreal) involving both graduate students and experts from industry. These case studies, which will be detailed in chapter 4, present an interesting blend of differences in many aspects: experience of the participants, monitoring environment, type of design, position in the product life-cycle, etc. In fact, the retrospective construction of the DTM research approach presented in figure 1.8 was largely influenced by the monitoring environment.

2.2.1. Rationale for the DTM research approach

The DTM research approach is strongly based on the Observe-Analyse-Intervene cycle proposed by Tang (1989). This methodology, also referred to as interaction analysis (Tang and Leifer 1996), was developed to efficiently observe design team activity. As mentioned in §2.1, it can be considered as a action research approach, although in the case of interaction analysis the research team is not necessarily from the same domain of activity as the group of individuals under study. Indeed, in the engineering design research domain, research teams are often a mix of researchers from a variety of backgrounds: engineering, computer science, cognitive science, psychology, linguistics, etc.

The "intervene" element of the "Observe-Analyse-Intervene" cycle blends a slight prescriptive approach within an overall descriptive method. This technique collects videotaped data and analyses it without knowing exactly what needs to be examined. It usually involves a small group of designers in a dedicated setting where recording facilities do not impede the work of the participants. The data is then used for investigation and appropriate intervention. Once the findings are outlined, another interaction analysis cycle can start.

Nevertheless, the interaction analysis cycle felt somewhat incomplete to be used as such in this research. The main reason for this is the context in which the observations were made. Tang (1989) developed this method for a specific design environment: a dedicated room at Stanford University with sophisticated audio/video equipment where designers could be monitored. Only in one of the case studies reported here was it possible to recreate a comparable environment: the students in the CAMAQ project worked in a room fully equipped with the latest collaborative engineering tools (CAD, PDM, and many analytical tools), which are only available to them in restricted space. However, even in this more favourable case, the observation equipment and strategy had to be developed and installed properly.

2.2.2. Developing the DTM research approach

It is from this apparently small difference that emerged the need for a more complete view of the research effort: the DTM research diagram presented in figure 1.8 effectively illustrates that there are quite a few iterations and steps before even being able to efficiently observe the phenomenon, hence entering the Observe-Analyse- Intervene cycle.

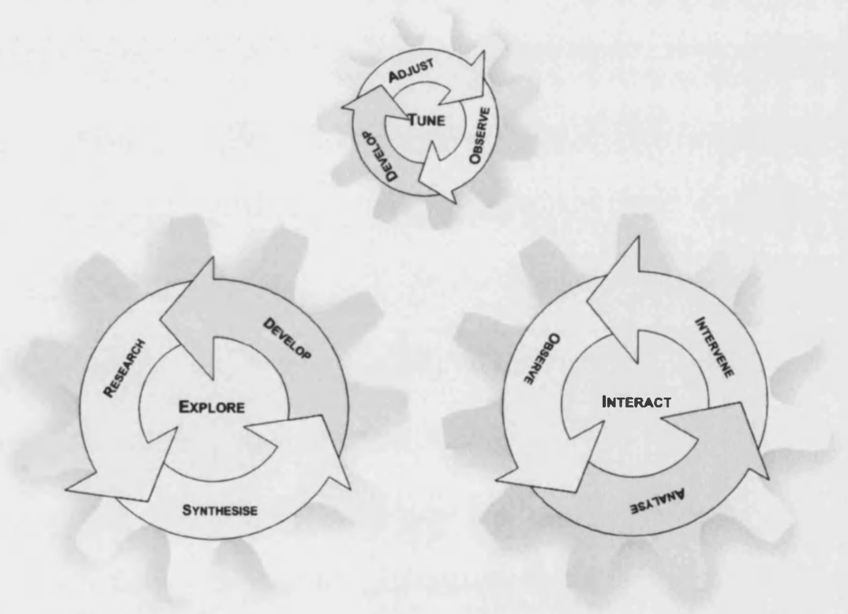


***Figure 1.8** The DTM research approach.*

The DTM research approach is composed of three cyclic motions: explore, tune, and interact. The exploration part of the research process is probably common to most disciplines; it is about positioning the work in accordance to past research ("research"), gaining an overall view of the domain of study ("synthesise"), and appropriately using past findings in a new context ("develop"). The tune cycle, in figure 1.8, has been represented as a smaller gear than the two others. This illustrates a higher iteration speed of the process, where the theoretical techniques and approaches developed from the "explore cycle" ("develop") need to be adjusted ("adjust") to the observations ("observe") made in the "interact cycle". Finally, the "interact cycle" refers to the interaction analysis approach detailed previously.

The 3 DTM research cycles constitute a naturalistic observation approach and are hence mainly descriptive. They integrate the interaction analysis method but also focus on the various facets of *in situ* observations. Here, the observation step can take place either in a mock-up environment or the researcher can observe the design team in their work environment, which is evidently a configuration more complicated to set up.

2.2.3. Customising the DTM research approach for each case study

In practice, the three case studies monitored during the DTM project fulfilled different objectives:

- The student project at the University of Bath helped to adjust the monitoring techniques using simple recording equipment. Here the methodology was purely explorative and the naturalistic observation was essentially directed towards the understanding of participant behaviour when monitoring equipment is introduced in the work environment.
- In the Airbus UK case study, the most important one, the data was collected on site with engineers working on real projects. A Preliminary Design Review (PDR) and a Requirement Review (RR) taking place on different projects were monitored. Of course, the use of complete recording equipment was limited to audio only. Also, the "intervene" element was forced out of the research cycle to avoid disturbing the engineers. The research approach was therefore once again very descriptive but the objective was different: collect data from a real design review situation in situ (in the engineers' natural working environment). The data collection taken from these two distinctive aerospace design reviews is quite unique, and the negotiation and management of such a feat was, as one can imagine, a long, difficult, but ultimately rewarding experience.
- The CAMAQ project provided valuable analytical data and a setting where the three research cycles could take place. The monitoring equipment was complete with cameras to record the transactions. Here, the author was not only an observer but also a participant. His double role as communication manager and member of the systems integration team (fuel line specialist) provided an ideal opportunity to gather all the necessary data and to gain a deep understanding of the engineering

issues faced by the team. Some of the tools, techniques and findings of this research were trialed by colleagues to complete the "interact" cycle. In this case, the research approach can clearly be considered as an action oriented research, where the author was part of the team of individuals under study.

2.3. Research questions

The research methodology described in the previous section enabled to efficiently use the empirical data collected from the case studies and the findings from the literature to answer a number of research questions which constitute the underlying rationale for the work reported in this thesis.

The overall guiding question for this thesis is:

How is it possible to record design review meetings to capture the important knowledge elements for further reuse?

This chapter has so far detailed the context of the research reported here, where design reviews have been defined in an aerospace and CE context. More specific questions also need to be answered to complete the task:

What types of communication and information processes occur during meetings?

How is it possible to analyse design discourse?

What is a meeting? What characterises a design review and the transactions that take place there?

What are the available means to capture information during meetings?

What are the important knowledge elements that are not currently captured during design reviews?

Can design reviews be managed more efficiently?

How should the knowledge elements be made available to designers for reuse?

These research questions are not the precise topic of any of the following chapters but will be gradually answered in this dissertation. Some of them will only be given a partial answer or a framework to further the reflection. However, they all take part in the momentum driving this research and contribute in themselves to the reader's understanding of the problem.

2.4. “Research circuit”

This last section outlines the main research activities that were carried out over the past four years to fulfil the research goals expressed by the set of research questions summarised in §2.3. Figure 1.9 reveals a map of activities, named “research circuit” because of its visual similarity with electronic circuit boards and the circular or iterative nature of many of the activities. The “research circuit” is placed over the three main research cycles of the DTM research methodology, highlighting the iterative nature of the activities which is not reflected by the circuit itself.

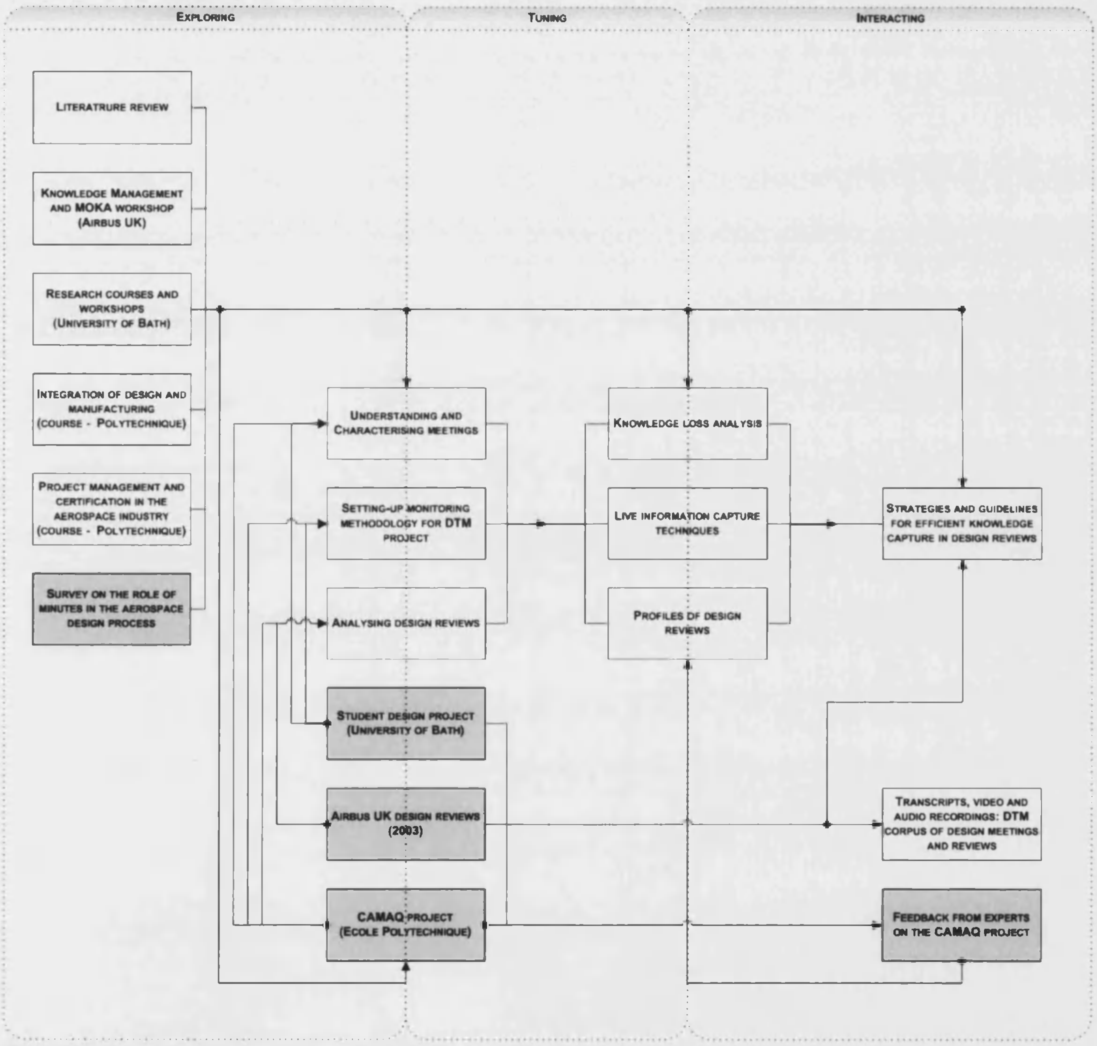


Figure 1.9 *The DTM “research circuit”*

The grey activity boxes represent new sources of data and information generated by the needs of this research; these include three case studies and two surveys. The case studies constitute a unique corpus of design meetings with audio or video recordings augmented in some cases by verbatim transcripts. The two surveys gave the author a perspective from the user point of view. A first questionnaire (available in appendix G) was distributed to several major aerospace companies to evaluate the role of design review minutes in the product development process; the results are presented in chapter 6. The other survey, reported in chapter 4, was developed for the industry experts reviewing the CAMAQ project and provided feedback on how the student work compared with industrial practices in terms of content and process.

Finally, the "research circuit" does not account for reporting activities, which have taken place throughout the research. Regular reports, presentations and videoconferences were part of the communication strategies adopted by the author to disseminate progressively the information and findings to the industrial partners, the academic supervisors and colleagues.

READER'S GUIDE TO THE THESIS

The following chapters will continue to discuss the findings from the DTM research project within the engineering design context described in this introduction.

Chapter 2 ("communication and information processes in engineering design") deepens the literature review on the specific topics of communication and information processes in engineering design activities. The concept of knowledge and its implications for organisations are also introduced in this chapter.

Chapter 3 ("the study of design meetings") focuses on the event central to this research – the meeting – and proposes a detailed understanding of its constitutive elements based on both an object-oriented meeting model and a process-oriented meeting model. A comprehensive review of information technologies developed for collaborative situations such as meetings completes the contents of this chapter.

Chapter 4 ("new approaches to analyse design meetings") presents the analytical tools developed for the purposes of this research: the Transcript Coding Scheme (TCS) enables an analysis of verbatim transcripts, the Meeting Capture Template (MCT) proposes similar results but offers the possibility of coding the meeting "live" without a transcript, and the Information Mapping Technique (IMT) can be used to analyse the loss of important knowledge elements in the minutes of design reviews.

Chapter 5 ("results from the DTM case studies") analyses the academic and industrial case studies with the 3 tools presented in the previous chapter. The results are presented in terms of observed communication, information, and knowledge processes. Ultimately, this chapter illustrates new means to monitor and analyse engineering meetings.

Chapter 6 ("a knowledge-based strategy for design review records") proposes a framework for the extended capture of key knowledge elements in design reviews based on an action-oriented strategy. Special attention is given to the reuse of the captured knowledge elements and a number of practical solutions are put forward by the author.

Chapter 7 ("conclusion and future work") concludes this dissertation by offering a summary of the research findings and contributions, their implications, and possible areas for future work.

CHAPTER 2

INFORMATION AND COMMUNICATION PROCESSES IN DESIGN ACTIVITIES

For the aerospace industry, the value of improving communication, information, and knowledge processes within design activities is multiplied not only by the number of teams working on the product, but also by the nature of the design activities. The design review process has been described in the previous chapter within the context of product development processes and practices. Nevertheless, little has been said about how engineers interact during this specific design activity.

Essential aspects concerning the nature of design activities and the communication processes in multidisciplinary product development teams will therefore be introduced in this chapter. Then, a reflection on the existing pools of information and an understanding of current information handling behaviours observed in engineering teams will be presented. Finally, from an analysis of the literature related to Knowledge Management practices, three key elements will be singled out for the efficient knowledge-oriented recording of information exchanges during design reviews: rationale, decisions, and lessons learnt.

1. DESIGN ACTIVITIES

The study of engineering design meetings is at the crossroads of several research fields: engineering design, social studies, and organisational strategies. Yet, a common framework to study human practices, regardless of the domain of research, has been to observe the activities involved. According to Kuutti (1995):

> *"An activity is a form of doing directed to an object and activities are distinguished from each other according to their objects. Transforming the object into an outcome motivates the existence of an activity."*

The object of a design review, as mentioned in chapter 1 (§1.2.2), will vary according to its position in the product life-cycle, but will always concern the validation and verification of the design achievements and their related processes. The outcomes of a design review will hence invariably influence the activities involved in the product development process until the next review takes place. Therefore, the impact of the design control process, embodied in design reviews, can only be truly understood within the context of design activities in general. The following sections will present how the activity linked to design, as a whole, can be approached, and also how it can be generally decomposed in more specific sub-activities. These theoretical views will be illustrated and refined using examples from the aerospace engineering domain.

1.1. Classes of design

An interesting aspect of engineering design research is the overall classification for the typical activities involved in the design process. Numerous researchers have suggested the need to distinguish between 3 generic classes of design activities in order to develop efficient design tools and methodologies (Cagan and Agogino 1991):

- *Original or Creative design:* this class of design activity involves the elaboration of an original process or product not previously in existence. Original design (Pahl and Beitz 1984; Ullman 1992) is sometimes referred to as creative (French 1988; Gero and Maher 1993)
- *Adaptive design or redesign:* this type of design activity involves adapting a known system, or the modification of an existing product to a changed task (Ray 1985). Here, the innovative design of certain constitutive elements of the product is often called for (Cagan and Agogino 1987; Dym 1994).

- *Variant or routine design:* routine design is understood as the class of designing where all the design or structure variables and all the performance or behaviour variables are known. What is left to be done is to determine values for the structure variables (Gero and Maher 1993).

This global classification is interesting as it suggests two types of postures that the designer can take on a project: he or she can create or adapt. The notion of originality in mechanical engineering design is very questionable as Yen (2000) argues in his introductory thesis chapter:

> *"My academic advisor, Professor Larry Leifer has often stated: "All Design is Redesign". Whether or not one believes this literally, most can agree that design is at least inspired or influenced by previous effort."*

Even if this statement can be seen by some as polemical or even extreme, it remains verifiable to a certain extent and is an interesting observation for this research and even for the whole of the community working on information for design engineers. Indeed, a lot of their work involves using previous designs to adapt them or inspire a new creation. In the automotive industry for example, up to 80% of the design work is considered of a routine nature even though new products are brought to the market each year (Sellini 1999). Figure 2.1 highlights this trend by offering a quantifiable perspective on what is effectively meant by the use of the term "new product" as the outcome of the product development activities.

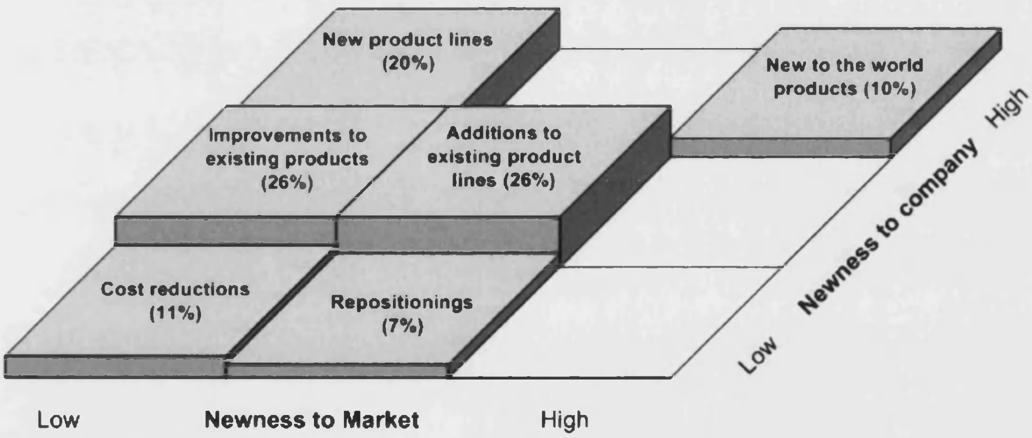


Figure 2.1 *Different types of "new" products (Cooper 2005)*

The grid suggested by Cooper (2005) and reproduced in figure 2.1 shows the two dimensions of the term "newness", i.e. newness to market and newness to company, and places six types of new products accordingly. The definitions for the six categories, i.e. "new product lines", "new to the world products", "improvement to existing products", "additions to existing product lines", "cost reductions", and "repositionings", can be found in Cooper (2005), the percentages are taken from Booz-Allen & Hamilton Inc. (1982) and from the latest American Productivity and Quality Center study (Cooper et al. 2003). Ultimately, the matrix clearly shows that innovation in engineering design, categorised as "new to the world products", is only really present in some 10% of the products developed around the globe.

In the specific case of this research, the monitoring of aerospace designers will almost invariably give insights on adaptive and routine design with engineering work mainly directed towards the development of the following type of products: "cost reductions" (e.g. integration of composite parts in aircraft structures since the early 1980s), "improvement to existing products" (e.g. the Airbus A300-600 replaced the A300B4 in 1984), "additions to existing product lines" (e.g. the addition of the Airbus A340-600 to the A340 family in 2002) and "new product lines" (e.g. the Airbus A380 family).

1.2. Nature of aerospace design activities according to the aircraft component level

Given the complexity of an aircraft, a more refined classification of aerospace design activities can be made according to the component level which is under consideration. An aircraft is typically decomposed into major assemblies (e.g. the wing), sub-assemblies (e.g. the engine pylons) right down to component level (e.g. the spar). For each one of these aircraft levels, predetermined by the aerospace manufacturer, different product development teams are organised to produce the final designs. These teams follow standard product development and CE principles outlined in chapter 1, and are controlled by similar design reviewing processes. Nevertheless, the nature of the activities involved will differ significantly according to the position of the component or assembly under development in the overall product structure. In fact, at a component level, most aerospace design activities will be of a routine nature, but some parts will nonetheless incorporate a small number of innovative features. On the other hand, at a higher aircraft component level, the design can usually be considered as adaptive or even creative when considering design management and evaluation activities; the current product development environment described in chapter 1 and the ever increasing constraints imposed by aircraft certification regulations are constantly pushing the limits of engineers' creativity and resourcefulness when it comes to managing and controlling the design.

1.3. A generic classification of design activities

The previous section has implicitly suggested the existence of a classification of design activities (e.g. design management, design control). Table 2.1 describes a generic classification of design activity categories presented by Sim and Duffy (2003).

***Table 2.1** A classification and description of generic design activities*

Design Activities	Description
Design definition	**Manage the evolving design while defining it until production**
Abstracting	Simplify the complexity of the design object
Associating	Generate new concepts through association of concepts
Composing	Combine concepts to satisfy overall function
Decomposing	Break down task/problem/object into a setoff independent entities
Defining	Make definitive descriptions of the design
Detailing	Remove ambiguity for the manufacture and assembly of the design
Generating	Generate solutions to customer requirements
Standardising	Reduce number of components to design and reduce manufacture cost
Structuring/integrating	Optimise product architecture to minimise complexity of total product
Synthesising	Assemble all the elements to reach totality in the design of a product
Design evaluation	**Analyse and evaluate design solutions to reduce design solution space**
Analysing	Predict the behaviour of a design
Decision making	Choose the best alternative from a set based on predefined criteria
Evaluating	Measure the quality or value of the design solution
Modelling	Model the design to provide a perspective on a specific aspect of the product
Selecting	Choose a feasible design solution or activity from a set of alternatives
Simulating	Use models to form an imitation of the behaviour of the artefact
Testing/Experimenting	Verify actual behaviour against expected behaviour
Design management	**Manage coordination of activities related to the design and its processes**
Constraining	Reduce the complexity of the design space
Exploring	Explore the design space without committing to some solutions
Identifying	Identify means to achieve the design (past designs, methodologies, tools)
Information gathering	Update relevant information for completion of the task
Planning	Streamline resources for design tasks to reduce time to market
Prioritising	Focus on important goals with influence on downstream design activities
Resolving	Resolve conflicting interests, requirements and viewpoints
Searching	Satisfy requirements of the design solution
Decomposing	Maximise decoupling of activities into tasks to reduce design iterations
Scheduling	Time stamp design tasks to reduce time to market

Source: Sim and Duffy (2003)

In fact, there are many views on how the overall activity of design can be broken down into sub-categories and most are inspired from the various models of the design process, which have been reviewed in chapter 1. Sim and Duffy (2003), as shown in table 2.1, propose a constructive and unifying summary of these different perspectives through a set of generic design activities aimed at attaining an acceptable level of ontological completeness. Conceptualising the activity of design at the level of granularity presented in table 2.1, with three main categories ("design definition", "design evaluation" and "design management") and their respective sub-categories, offers a generic decomposition applicable to any design project. As most product development models have essentially focused on the early stages of the process (see Chapter 1, §1.1.1), it is not surprising that this categorisation essentially describes the design activities, especially the "design definition" category, from a designer's point of view.

For the study of design reviews, the "design evaluation" and "design management" categories offer relevant descriptions of some of the core activities and goals which are expected to take place during these specific meeting events. The proposed classification outlined in table 2.1 presents a solid framework to understand engineering design practices in the early stages of the product development process and can effectively guide research and development of design support systems (Sim and Duffy 2003).

In the context of design activities, engineers use, transform, create, and communicate valuable information and knowledge. For the aerospace industry, the value of improving communication, information, and knowledge processes within design activities is multiplied not only by the number of teams working on the product but also by the nature of the design activities. The efficiency of adaptive and routine designs is highly dependent on the management and communication of existing information and knowledge. The following sections will therefore review the typical characteristics of design project team activity in terms of communication processes (section 2), information (section 3), and knowledge (section 4).

2. COMMUNICATION PROCESSES IN ENGINEERING DESIGN

Communication is a concept which does not really adhere to a straightforward definition. To avoid any philosophical debate on what is communication, it is often preferred to define the word in its context. It is easier to talk about a communication process (Eckert *et al.* 2005), where "communication process" is understood in its most generic sense: *a description or explanation of the chain of events involved in communicating information from one party to another.*

The communication dimension within a multidisciplinary engineering team, as suggested by the CE principles, creates barriers in the product development; communication barriers emerge from the use of different professional languages, and from knowledge and interests in domains which sometimes have little in common (Bucciarelli 1988, Valkenburg 1998). Understanding the current mechanisms involved in communication processes within engineering design teams is most definitely the best way to ultimately prevent and solve design issues related to communication breakdown. As reported by Eckert *et al.* (2005), research leading to communication theories can be grouped in three distinctive areas: information-, interaction-, and situation-centred theories. These approaches look at different aspects of the communication process. Information-centered theories look at internal processes used by each participant, interaction-centred theories focus essentially on the relationships between participants, and situation-centred theories are concerned with the impact of the environment on the communication process.

It is not the intent of this section to list communication barriers reported in previous research but rather to forward the generic concepts used in this field for the purpose of analysing communication processes in a specific situation: engineering design reviews.

2.1. General aspects of communication processes in engineering design

The natural human communication channels are audio, visual, and tactile. Of course, all three channels are used in human communication situations, but certain particularities exist when engineering design activities are considered.

A useful terminology often linked to the act of communicating in general is synchronicity, which defines the relationship between different things according to time. Synchronous communication is a communication process in which messages are exchanged during the same time interval. For example, Instant Messaging is a type of electronic communication in which the participants must be at the computer at the same time to share information.

Asynchronous communication is a communication process in which messages are exchanged during different time intervals. For example, e-mail is an asynchronous type of electronic communication because two people do not have to sit at the computer at the same time to share information. Table 2.2 lists the main communication technologies used in the workplace along with the communication channel and synchronicity type expected for each one.

Table 2.2 *List of typical communication technologies used in the workplace*

Technology	Communication channel(s)	Synchronicity
Telephone	Audio	Synchronous
E-mail	Visual	Asynchronous
Instant Messaging	Visual	Synchronous
Online forum	Visual	Asynchronous
Videoconference	Audio / Visual	Synchronous

Of course, the technologies listed above can be used in alternative ways; a teleconferencing kit will enhance a normal telephone and transform it into a technology which supports group communication. An answering machine will enable the user to have an asynchronous conversation with his counterpart. Instant Messaging (IM) can easily be used as an online forum because IM technologies memorise the history of certain conversations. Overall, the technologies presented in table 2.2 provide an essential support for team members to communicate remotely (whether the destination is the office next door or the supplier based in another country).

Communication processes in engineering design have certain particularities. The first that often comes to mind is the use of common references between designers (Bly 2003, Eckert *et al.* 2003). These references can be of an explicit nature requiring the support of specific design artefacts (parts, drawings, documents, computer based models, similar designs etc.) or of a very implicit nature described with only a few words (e.g. reference to standard parts). In effect, the nature of the design (creative, adaptive, or routine) will largely impact on the nature of the references used between designers to communicate. Explicit references will be necessary throughout the design process for an innovative product or feature, while common references (of an implicit nature) will be immediately shared between stakeholders in the case of a routine design.

Another important aspect of design communication is the relationship between verbal communication and sketching. Yen (2000) noticed in his research that "*it is common to augment speech with sketching and gesturing in design communication*". It has to be argued that these findings took place in a specific context: the research project focussed on the conceptual phase of the design process, where most of the verbal communication between design engineers is linked to sketches or diagrams. As suggested earlier in §1.3, the use of common implicit references for many routine design components in an aircraft will lead to the use of CAD models rather than sketches very early on in the design process. It is therefore probably more adequate to suggest that, at least in the aerospace design domain, one of the characteristics of speech is that it is invariably augmented by a form of visual stimuli (3D models, sketches, documents, gestures, physical parts etc.).

2.2. Communication process models in engineering design teams

Medland (1992) observed through case studies of design activities being undertaken in different industrial firms that the designer performed within four separate communication process models, formally or informally acknowledged by the company. Eckert *et al.* (2005) propose a slightly different view of these communication process models based on the designer's point of view. Table 2.3 offers a constructive summarisation of both perspectives, joining the four categories found from a company's point of view ("delegation model", "reporting model", "awareness model", and "problem handling model") to the three communication model types observed from a designer's perspective ("handover", "joint designing", and "interface negotiation").

The "handover" scenario is typically found when designers are assigned to an individual and well defined task. The "handover" model is usually present in the detail design stages of the product development process, when tasks are well defined or when designers are confronted with the routine design of a component. When the design is carried out by a contractor or a supplier, a formal "reporting" of the work will be requested by the client and could lead to an "interface negotiation" if problems are uncovered. The "handover" scenario is associated to specific "design definition" activities (see §1.3).

"Joint designing" is used in many design situations where problems arise and are solved through formal contacts (stakeholders within the same project) or informal networks of experts (within or outside the company). Most design activities can require a "joint designing" communication scenario, especially when problems arise and need to be solved rapidly through informal contacts.

"Interface negotiation" can be seen as a formal problem handling situation and is the communication model which can be observed during design reviews. Eckert *et al.* (2005) have defined 6 types of "interface negotiation" discussions which can take place between designers: "request for information", "negotiation for clarity and negotiation of constraints", "idea generation", "conflict resolution", "decision making", and "justification". Of course, these types of discussions can all take place during the same meeting regardless of the objective of the event, and will typically involve "design evaluation" and "design management" activities (see §1.3).

Table 2.3 *Summary of communication process models reported in engineering design*

Designer view	**Company view**	**Description**
Handover	Delegation model	The "handover" is a scenario in which a person passes on the work to another specialist in an asynchronous communication mode. The "delegation model" represents the hierarchical structure of responsibility found in companies. In design, this can be the reception of the necessary instruction that defines the objectives and gives authority to proceed on a predefined task.
	Reporting model	The "handover" is a scenario in which a person passes on the work to another specialist in an asynchronous communication mode. The "reporting model" formally presents the results of the subordinate task, defined in a "delegation" type model, through a written report.
Joint designing	Awareness model	The "joint designing" is a scenario found in design tasks where problems are solved by a team of experts, who are assigned to work on the same problem. The team is usually collocated and communicates in a synchronous mode. The "awareness model" acknowledges the fact that in many cases, informal contacts are necessary to help solve specific issues.
Interface negotiation	Problem handling model	"Interface negotiation" scenarios are often observed in concurrent engineering situations, where various people from different fields of expertise are formally invited to share individual problems in order to achieve consensual solutions. Designers communicate synchronously to fulfill the task. The "problem handling model" describes the need for different teams working on a same project to share their views in order to solve common problems. Design meetings are an ideal event to observe this type of communication model.

Source: "designer view" from Eckert et al. (2005), "company view" from Medland (1992)

3. INFORMATION PROCESSES IN ENGINEERING DESIGN

Court *et al.* (1998) found that design engineers spent 20 to 30 percent of their time acquiring, using and communicating information according to the results of a survey which covered 300 respondents. It is widely established that engineering, like other disciplines, relies heavily on information in order to achieve its goals (Baya 1996, Ward 2001, Yang 2000). Engineering design is often considered as an information intensive process, where all activities and operations need information to succeed (Baya 1996). By improving the spectrum of the information available, its capture, selection and reuse, organisations will improve the quality and performance of their products but also bring them sooner to the market place.

With the continuous growth of available information in the workplace, "overload" has become a common denominator to qualify the vast amount of information made accessible for engineers. Nevertheless, it can be argued that information overload is not so much a problem of quantity but rather one of quality (Simpson and Prusak 1995). Defining and characterising the nature of information needed by design engineers is essential for the development of efficient information management systems.

Information is not an easy concept to define. Often erroneously used as a synonym to data or knowledge, information has been described in many different ways. For the purpose of this thesis, the overall definition suggested by Hoffmann (1980) will be used:

> *"Information is an aggregate (collection, accumulation) of statements, of facts and/or figures which are conceptually (by way of reasoning, logic, ideas or any other mental mode of operation) interrelated (connected), or in shorthand, as a formula: information = Facts, Figures, + their meaningful connections."*

As a result of this definition, the concept of data simply covers facts, figures or statements. Consequently, information can quite simply be defined as an accumulation of data interrelated by meaningful connections.

Another interesting definition of information taken in the precise context of ordinary discourse has been reported by Derr (1985), where information is seen as:

> *"An abstract, meaningful representation of determinations made of objects. Furthermore, it has been concluded that information has derivative properties which enable it to communicate, inform, empower and to exist in some quantity."*

From the object-oriented perspective proposed by Derr (1985), information is quantifiable and can therefore be represented through computer-based technologies, often referred to as Information Technologies (IT).

Nonetheless, the ambiguity surrounding the notion of information stems more from the context in which it is used than from its definition. Buckland (1991) outlined three different situations in which information is typically used: "information-as-process", "information-as-thing", and "information-as-knowledge". These different dimensions of information are based on the definition found in the Oxford English dictionary (1989). In this section, the concept of information will be taken in the context of the workplace, where information elements are treated as objects ("information-as-thing"). For example, documents or even data can be regarded as information elements provided that they are considered to be informative (or instructive). Critical features of information such as the format, the structure, the type, and the source will therefore first be summarized. The use of information and its processing ("information as process") during design activities, which can also be defined as the "act of informing", will complete the overview on the topic of information in engineering design. Section 4 will be dedicated to the more recent dimension given to information: "information-as-knowledge" which can only be externalised by "information-as-thing" elements in the act of informing.

3.1. Critical features of information

In the design community, information is often described according to its format and structure. The format defines the communication channel and ultimately the medium used to convey or imbed the information. These various formats have been listed in Table 2.4 along with the related communication channels and media.

***Table 2.4** Information formats*

Communication channel	Information format	Examples of media
Visual	Textual	Paper documents, numerical documents, email
	Pictorial	Drawings, Sketches, CAD models
	Gesture	Videoconference, face to face
Audio	Verbal	Telephone, videoconference, face to face
	Intonation	Telephone, videoconference, face to face
Tactile	Physical contact	Face to face (physical object or person)

In a face to face situation, such as a meeting, all six formats may be used to communicate information between participants, but verbal, intonation, and gesture formats will clearly dominate the information process during the event. Intonation adds to the verbal format by expressing approvals, indifferences, or dislikes which can be crucial during a decision making process. Gesture includes body motions and facial expressions and has been found to add significant richness to speech in many engineering design situations (Yen 2000). Physical contact with the designed part or assembly is also very important for engineers as some problems or defects are only detected once the design actually "comes to life" in a material form; the need for this information format has made rapid prototyping and more recently virtual reality the final control mechanism for the design to enter the production phase (Davies 2000).

From the various information formats presented above, it now seems clear that the "*information-as-thing*" dimension forwarded by Buckland (1991) is well suited to define design information. Design information is not only conveyed through verbal, textual and pictorial formats but also through objects and people.

Along with the format, a common feature often referred to is the structure or formality of the information. Although the terms formal and informal are commonplace in the literature (Culley and Allen 1999, Hicks *et al.* 2002), the author believes that structure, *"the arrangement of and relations between parts or elements of something"* (New Oxford American Dictionary 2005), is sometimes a better qualifier when evaluating information. Usually, the level of formality of information in the context of company information processes would simply suggest that the information was imbedded following a certain set of company rules. Nevertheless, in most situations, the terms "formal" and "informal" information can be used as synonyms to the terms "structured" and "unstructured" information.

In practice, an information element can be randomly situated along a global information structure spectrum, which cannot in any way be described by a mathematical formulation, but can be scaled by describing its extremes and an intermediate point. In his thesis, Gardoni (1999) gives useful definitions of structured, semi structured, and unstructured information; these have been adapted and placed along the information structure spectrum (Yang 2000) depicted in figure 2.2.

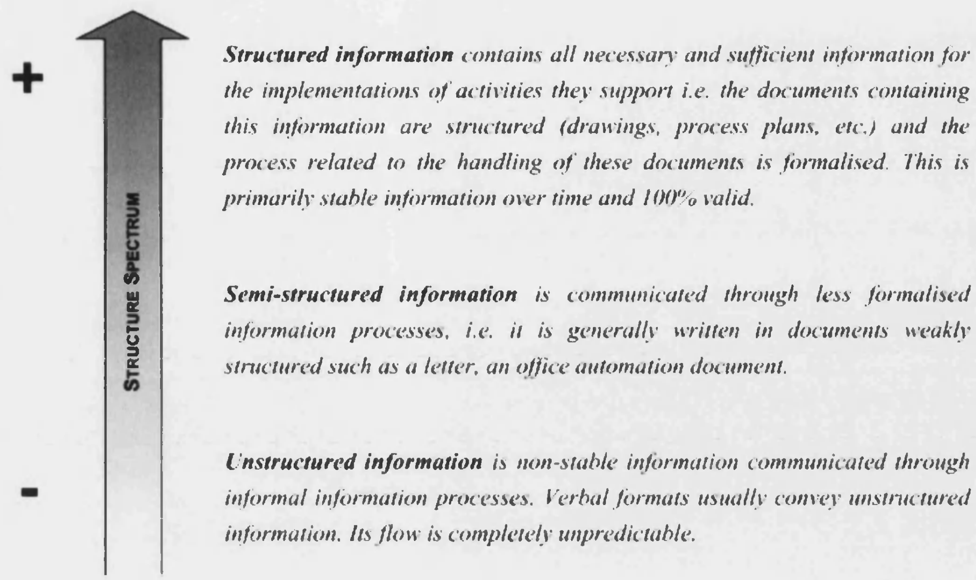


Figure 2.2 *The information structure spectrum. Spectrum based on Yang (2000); definitions based on Gardoni (1999).*

The structure of information is a key aspect for its effective flow within a given company. As suggested in figure 2.2, structured information is well adapted to formal information processes whereas, on the other end of the spectrum, unstructured information will flow informally and unpredictably. Lievrouw and Finn (1996) concluded that informal flows carrying unstructured information are usually linked to a certain degree of creativity and a need for consensus through synchronous modes of communication. Therefore, face to face situations such as meetings will inevitably challenge organisational information processes to capture the full richness of the created and exchanged information.

To further illustrate the definitions proposed in figure 2.2, table 2.5 lists a few examples of structured, semi structured, and unstructured information sources. These have been grouped according to the format in which they are primarily conveyed: textual, pictorial, and verbal. The other formats previously mentioned (intonation, gesture, and physical contact) express highly unstructured information but are not suited for capture by current information technologies (Hicks *et al.* 2002).

Table 2.5 *Examples of information sources and their relative position in the structure spectrum*

Information structure	Information format	Examples of related information sources
Structured	Textual	Program codes, multiple choice questionnaires
	Pictorial	3D CAD model, IDEF process map
	Verbal	ceremony speech
Semi structured	Textual	Report, form, letter
	Pictorial	Analytical graphs, product specification drawings
	Verbal	Interview with prepared questions, presentation
Unstructured	Textual	Annotations, personal notes, emails
	Pictorial	Sketches
	Verbal	Conversations, discussions, telephone calls

Table 2.5 introduces a new notion – the "information source" – often confused with the concept of "information type". To overcome this common misunderstanding, Court (1995) in his thesis has made a clear distinction between type and source in the context of engineering design information.

A "type of information" is "what" information is required to undertake a particular task. For example: a material strength, a production lead time, why a certain design was used in the past or how the design is to be installed in the working environment (Court 1995). An information type is representative of a category of information.

A "source of information" is "where" such information can be obtained. For example a textbook, a journal, a drawing, a colleague, etc. (Court 1995). An information source is a place, person, event or thing from which information comes or can be obtained. From the exhaustive list of information sources proposed by Hicks *et al.* (2002) for mechanical engineering, the terms person and event used in the previous definition must be understood in a broad sense; a person can be one's memory or might include a group of people (or even an organisation) and an event can also refer to a past experience.

Based on a survey carried out in a leading UK powertrain consultancy, Ward (2001) concluded that the engineers used sources generating unstructured information and sources generating structured information complementarily. Two typical scenarios can be drawn; unstructured information backed up by structured information elements or structured information explained in more detail using unstructured information elements. In the first case, a common example would be during a meeting when one of the participants answers a question and backs it up with hard evidence such as validated engineering data. For the second case, one can easily imagine an engineer explaining a certification requirement to a colleague using sketches and diagrams (Gardoni and Blanco 2003).

3.2. Information use in engineering design

Overall, understanding current needs and practices of engineers when it comes to handling information is essential for any company wishing to manage and store design information efficiently for further reuse. Based on a general model of information use, Choo (1998) concludes that *"information use is the selection and processing of information resulting in new knowledge or action."*

When searching for information, Hardy (1982) suggests that users are drawn to certain information sources because of their accessibility in terms of speed and content rather than the quality or amount of information they can provide. Engineers will typically use a cost versus benefit approach in their seeking behaviour. Ultimately, the information sought is used for a single purpose: decision making (Simpson and Prusak 1995).

An expression regularly associated to information search in engineering design is "information overload", which is often thought to be a direct consequence of the multiplication of information technologies made available for engineers. Nonetheless, as Anderson *et al.* (1997) argue, the level of uncertainty of the information which is being dealt with due to recent Concurrent Engineering (CE) practices is also a major contributory factor. As discussed in chapter 1, CE forces flows of uncertain information between tasks and based on an extensive survey of information practices in the U.S. aerospace industry, results conclusively show how engineers widen their search across information sources when faced with increasing levels of uncertainty in the information they use (Anderson et al. 1997). The incompleteness of the information between concurrent design tasks is typically managed by using rigorous risk management techniques where foreseeable errors are weighted and associated to an appropriate contingency plan.

As a direct consequence of CE practices, uncertain/unstructured/informal information is nowadays a major focus point for the research and development of improved information systems. In the aerospace industry, the statistical data collected by Kennedy *et al.* (1997) conclusively shows that oral and written information used to carry out design tasks are equally important. Verbal information can typically be associated with a low level of structure and these previous remarks on information use therefore reinforce the need for new information systems to cope with unstructured information. Information systems should therefore focus on adding value to the information they provide. Simpson and Prusak (1995) suggest that there are five attributes which determine information quality: truth, scarcity, guidance, accessibility, and weight.

> *"Truth is the degree of confidence which the user places in information acquired (...) Scarcity is the value of information which is new or is not freely available to competitor organizations or other potential users (...) Guidance is the extent to which information points the way to what action needs to be taken in a certain situation or set of circumstances (...) Accessibility is the availability of information to its potential users when needed and in a form which they can use (...) Weight is the factor which prompts the recipient to treat the information so seriously that he will act upon it." (Simpson and Prusak 1995).*

Several research projects have looked into capturing unstructured information communicated visually (e.g. sketches and annotations) along with the structured information elements they are associated with (Gardoni 1999, Yen 2000). Although design activities naturally thrive on visual information, it is important to note that, even in this context, speech is often sufficient to support effective communication and more research is therefore required for extracting and archiving verbal information exchanges (Whittaker 2003). In the context of meetings, a number of technologies such as speech recognition associated to natural language processing are under investigation for the effective integration of verbal information to current engineering IT systems; these technologies will be reviewed in chapter 3.

For the proper integration of unstructured information in formal information processes, research must therefore reflect on the value added to the existing pools of information. A quality-focused formalisation of unstructured information such as sketches or verbal conversations is essential for the development of new engineering information systems free of overload. Fidel and Green (2004) outline a practical classification of information sources based on two categories: human and documentary sources. As detailed previously, engineers can quickly access documentary sources of information but often back-up their findings by communicating with colleagues or experts, human sources. The efficient interaction between both these sources implies first a formalisation of human sources and then the development of combination mechanisms. The integration of the IDEA system (a novel approach to browse informal documents) to the EBoK knowledge base (support for sharing knowledge between communities of practice) is a good example of combining human and documentary sources and forwards promising perspectives for information system developers and users alike (Lowe *et al.* 2003).

3.3. An information blueprint for aerospace design reviews

From an information perspective, the product life-cycle can be represented or modelled according to four typical company-wide dimensions: the Product, the Process, the Resources, and the External factors (PPRE). In his thesis, Labrousse (2004) reviews extensively the PPRE "objects" and gives one or several examples of information modelling techniques suited for each one of them. Table 2.6 is an adaptation of this work where formal definitions and examples are summarised. It is important to note that in table 2.6, the last two columns are not related: "engineering system" proposes examples of computer systems or techniques typically used by the engineer to store the type of information under consideration, while "information modelling techniques" suggests conceptualisation approaches to model the information.

Table 2.6 *Primary product life-cycle information types*

Product life-cycle information type	**Definition**	**Engineering system**	**Information/knowledge modelling techniques**
Product	The result or output of the process. Products can be of several types: human, information, material or energy.	CAD/CAM, Product Data Management (PDM)	FBS, MOKA
Process	Spatial and temporal organisation of activities using specific resources for a determined output or product.	Process mapping	IDEF, UML
Resources	An element contributing to a process different from the output or product of the process. Resources can be of several types: human, information, material or energy.	Enterprise Resource Planning (ERP)	IDEF, FBS
External factors	Constraints of a predictable or unpredictable nature which influence the process, product or resource under consideration.		IDEF, MOKA

Source: definitions and information modelling techniques from Labrousse (2004).

FBS (Function Behaviour Structure) models (Gero 1990) are product design oriented, MOKA (Methodology for Knowledge Based Engineering Applications) knowledge models (Stokes 2001) have been developed for the automotive and aerospace industries to capture product and process information, and UML (Unified Modelling Language) is a widely adopted object oriented modelling language (Booch *et al.* 1998).

Information generated by external factors does not possess a dedicated engineering system, but is nonetheless often integrated in other tools and procedures which deal with product, process, or resource information. IDEF (Integrated Definition Language) models (NIST 1993) for example account for constraints and rules which are applied to a process; predictable external factors are usually included under this designation.

As suggested at the beginning of this section, design activities can easily be conceptualised as information processes with the engineer seen as an information processor (Kennedy *et al.* 1997). Based on this approach, a design review in itself can also be considered as an information process. Figure 2.3 illustrates an information blueprint of a generic design review process using an $IDEF_0$ modelling approach. This model was proposed by Airbus UK in 2003. All the elements surrounding the main activity box A0 can be viewed as information objects: "inputs" and "outputs" are design information transformed by the activity, "constraints/rules" are the external factors influencing the process, and "resources" contribute to the transformation of the input information into output information.

Of course, the examples of information elements presented in figure 2.3 will vary according to the specificities of each aerospace company. Nonetheless, the model proposes a generic view which will be further expanded in the next chapter in order to understand in detail the information mechanisms which can occur during an aerospace design review.

The blueprint highlights the richness of engineering design information exchanged during a reviewing process in the aerospace industry. This is not really a surprise as the communication processes which take place during aerospace design reviews are typically synchronous and the essential communication channel – speech – is a proven knowledge production tool (Dong 2006), systematically augmented by a visual stimuli (3D models, sketches, documents, gestures, physical parts etc.) (Yen 2000).

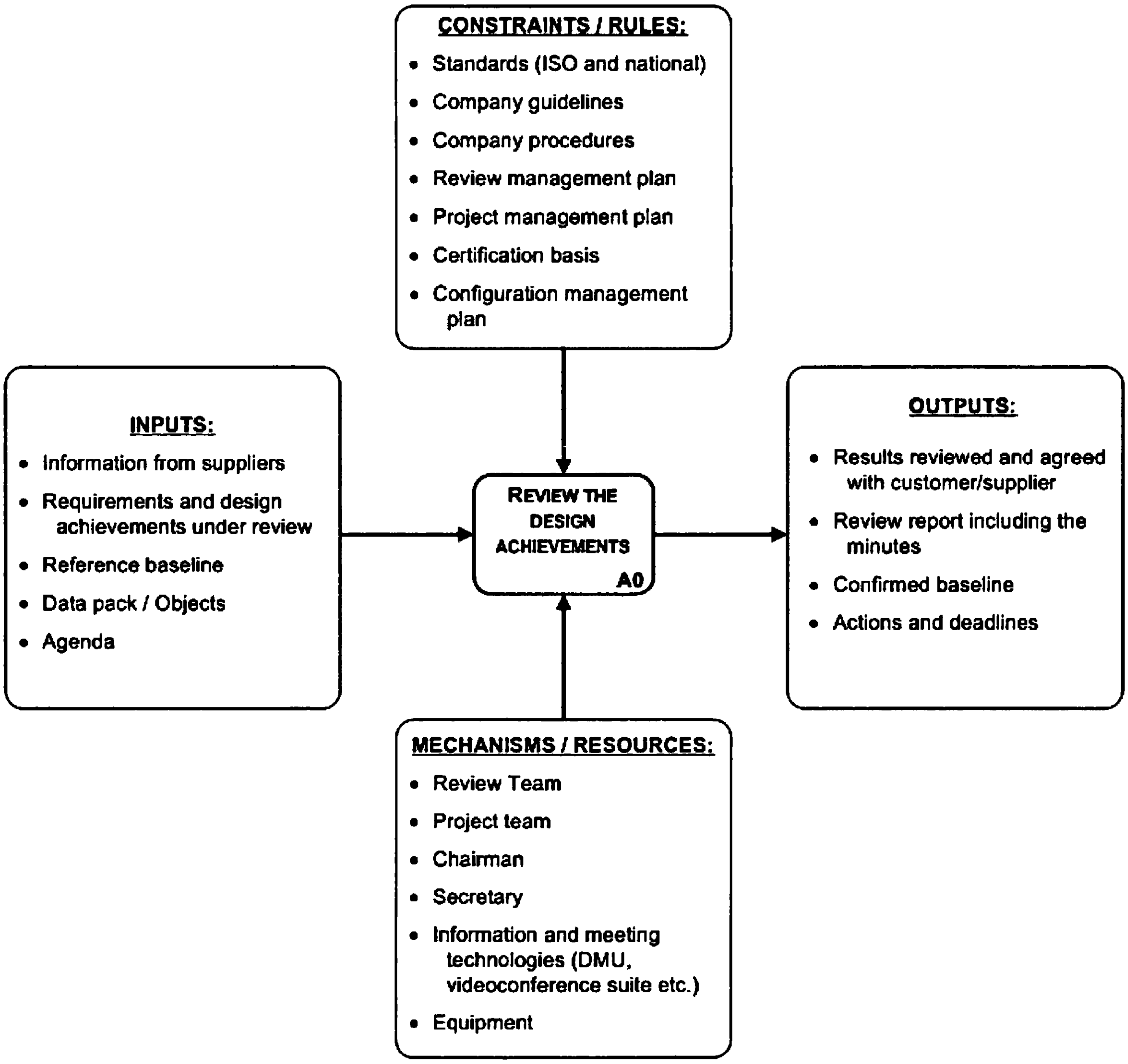


Figure 2.3 *Information blueprint for the aerospace design review process based on an $IDEF_0$ model*

4. KNOWLEDGE-ORIENTED PROCESSES FOR IMPROVED DESIGN INFORMATION REUSE

Interest in Knowledge Management (KM) is a simple consequence of the environment in which firms have to compete today, where new products need to be brought in ever more quickly to an ever growing market. Companies have therefore been drawn to evaluate and control what they know – their intellectual capital – to further enhance their chances of success and survival on the global market (Prusak 2001). The term "Information Management" has virtually been abandoned to solely describe the storage of information in computerised databases. "Knowledge Management" is now the important terminology when referring to reusable individual, project, or organisation memory.

The aerospace industry is of course a key player in the development of these new knowledge based engineering systems and methods. Aerospace engineering has focused on knowledge capture and reuse for two main reasons. First, as analysed in the previous sections, it deals mainly with redesign activities, where having to go through a whole design just to modify a few new features is very time consuming. The second reason is the invaluable loss of knowledge when experts leave the company, and the associated growth of contracting and work-sharing dispositions.

4.1. Information as knowledge

The concepts of information and knowledge are often misused as synonyms in everyday language. The reason for this is quite straightforward: knowledge is an intangible concept, often expressed in a physical way through information elements (signal, text, or speech) (Buckland 1991). As proposed earlier in section 3 of this chapter, information systems can only deal with information as objects. Marsh (1997) considers knowledge to consist of the assimilation of related information addressed in the context of a frame of reference, where this assimilation and frame of reference form the knowledge process. From these preliminary remarks, KM can effectively be viewed as the management of the specific information objects that take part in the company knowledge process. KM also addresses human-orieted aspects in a company such as training, communities of practice, etc. (Lowe *et al.* 2003).

There are many different perspectives on the definition of knowledge even in the engineering domain[1] and these are all valid, but because of this variety it is always necessary to define one's own point of view. The author therefore proposes the following generic definition of knowledge based on an interpretation of the one proposed in the New Oxford American Dictionary (2005).

***Knowledge** is the understanding and ideas inferred by a body of facts or information gathered by observation, education, or experience.*

This definition has also been influenced by the readings and experience gained throughout the research reported in this thesis. Along with knowledge, it is also important to propose definitions for strongly related concepts such as experience, wisdom, and expertise in an

[1] Court (1995), Aoshima (1996), Marsh (1997), Gardoni (1999), Sellini (1999), Liang (2000), Darlington (2002), Hicks *et al.* (2002), Labrousse (2004) are some of the readings which reflect the diversity of how knowledge is perceived in engineering design research.

engineering design context. Again the following definitions are adaptations of the ones found in the New Oxford American Dictionary (2005):

Experience *is the amount of skill acquired by practical contact with and observation of facts or events.*

Wisdom *is characterised by an ability to make a decisive judgement based on knowledge and experience.*

Expertise *is the level of wisdom attained by an engineer, built by exposure to problem handling situations.*

Reflection on the concepts of knowledge and experience has always brought conflicting views amongst philosophers. Nevertheless, it is important to step away from this timeless debate and simply recognise that knowledge and experience are intricately linked. Experience, in the sense defined previously, is sometimes referred to as experiential knowledge (e.g. Liang 2000).

Just like information, knowledge is a vast terminology and therefore can be divided into subcategories. An important classification when dealing with knowledge in engineering is the one related to the nature of the knowledge entity: explicit, implicit, or tacit. This terminology is widely spread across management and engineering literature even though explicit and tacit are the two attributes more commonly used (Darlington 2002).

Wallace *et al.* (2005) propose the following definitions in the context of engineering design practices:

> *"**Explicit knowledge** can be articulated, i.e. "written down" and stored externally in the form of information, e.g. in external repositories such as physical media, paper based media and electronic media."*
>
> *"**Implicit knowledge** cannot be articulated by the person possessing it. However it is possible to articulate it and store it externally after it has been extracted through knowledge elicitations methods."*
>
> *"**Tacit knowledge** is knowledge that, by common definition, cannot be articulated. However, its influence on the design process can be researched."*

The nature of the knowledge is the main influence for selecting an appropriate knowledge retention mechanism in a company. Explicit knowledge is materialised by information elements and can therefore be captured and managed in a documented form. Implicit or sometimes tacit knowledge on the other hand is only stored in individuals and sometimes better transmitted by simply bringing people together to work on a project (Aoshima 2002). These two approaches to KM have been defined by Lowe et al. (2004) as the "*codification strategy*" when knowledge is used as an artefact, and the "*personalization strategy*" when knowledge is transmitted from person to person in a strategic framework acknowledged by the company (e.g. communities of practice).

4.2. Company knowledge processes

Individual or personal knowledge is typically hard to articulate. Polanyi (1966) made a simple statement *"we can know more than we can tell"*, implying that an individual's knowledge is often of a tacit nature. Company knowledge is created through a conversion cycle which includes the tacit nature of individual knowledge. Nonaka and Takeuchi (1995) have proposed a widely acknowledged model of this cycle depicted in figure 2.4.

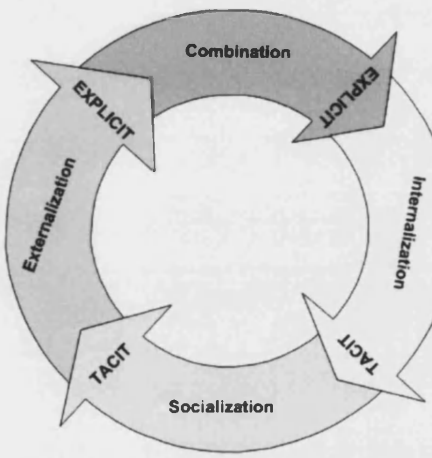


Figure 2.4 *Organizational knowledge conversion processes (Nonaka and Takeuchi 1995)*

The organisational knowledge conversion processes begin with *"individuals who develop some insight or intuition into how to do their tasks better"* (Choo 1998). This tacit individual knowledge is then socialised by sharing experiences between employees through training schemes for example. Collective activities such as conversations, group reflections etc. will then help externalise the tacit knowledge. The knowledge is made explicit by using information elements which can be documented and stored in company databases. Combination of various explicit knowledge sources is achieved through meetings, or telephone conversations which involve participants from different disciplinary backgrounds. Finally, "internalization" processes capture the experiences gained from the other knowledge processes to build on the individual's tacit knowledge base.

Although meetings are usually considered as an event in the combination process of company knowledge creation (Choo 1998), the variety of activities possibly involved in design reviews for example ("design evaluation" and "design management", table 2.1, §1.3) strongly suggest that design meetings play a role in both the externalization and combination knowledge processes.

The company knowledge creating cycle presented in figure 2.4 is part of a wider organizational knowing cycle. Figure 2.5 proposed by Choo (1998), links three different information behaviours: sense making, knowledge creating, and decision making.

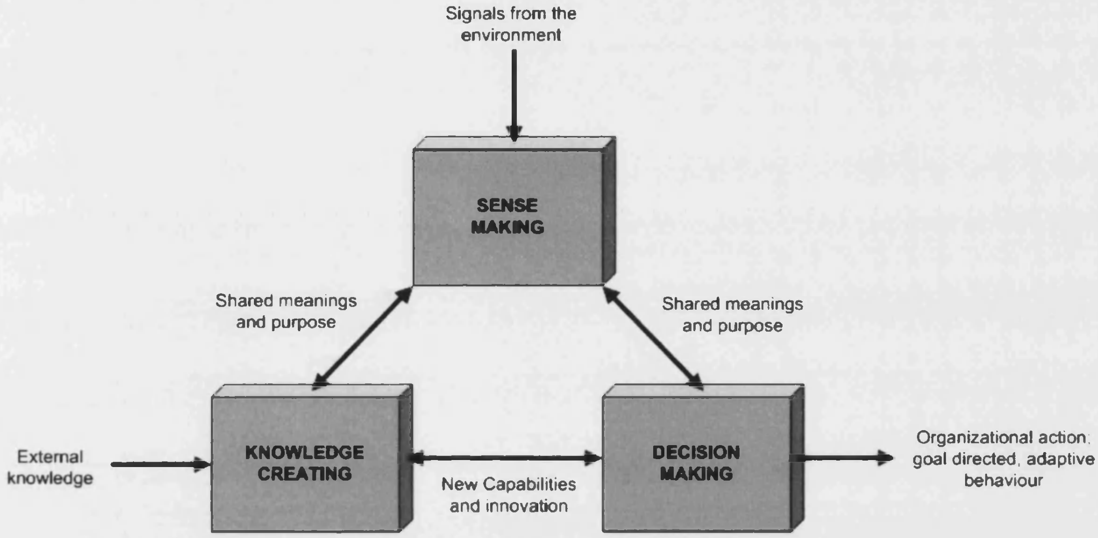


Figure 2.5 *The organizational knowing cycle (Choo 1998)*

The sense making process aims to develop a shared interpretation between members of an organisation based on what is happening around them (signals from the environment). Information is therefore interpreted, selected and retained. Once shared meanings and purpose are set, two possible paths can be outlined. If the situation is familiar, the organisation can start making decisions invoking previously defined routines and procedures. Nevertheless, the company may be facing a new or unrecognised situation and in this case the knowledge gap needs to be bridged using the knowledge creating cycle formalised by Nonaka and Takeuchi (1995). This knowledge will then feed the development of new decision structures to define the action to take or the behaviour to adopt.

The underlying point suggested by the knowing cycle presented in figure 2.5 is that an organisation is continuously learning in order to gain a competitive advantage in a fast changing economical environment. At a design activity level, this learning process has been conceptualised by Sim and Duffy (2004) and can ultimately be viewed as a knowledge gaining process. Figure 2.6 presents how learning and design activities are inextricably linked before, during or after the design process. Knowledge is stored in a memory; this is a generic term and can represent the individual's memory (tacit knowledge) or a company's database (explicit knowledge). The distinction between retrospective learning, provisional learning, and *in situ* learning might seem trivial but it actually influences what is learned and how (Sim and Duffy 2004). Figure 2.6 is a simplification of these three knowledge retaining processes and does not account for the internal mechanisms that occur within both the design and the learning activities and ensure the temporal knowledge interactions. These internal mechanisms are presented in greater detail by Sim and Duffy (2003 and 2004).

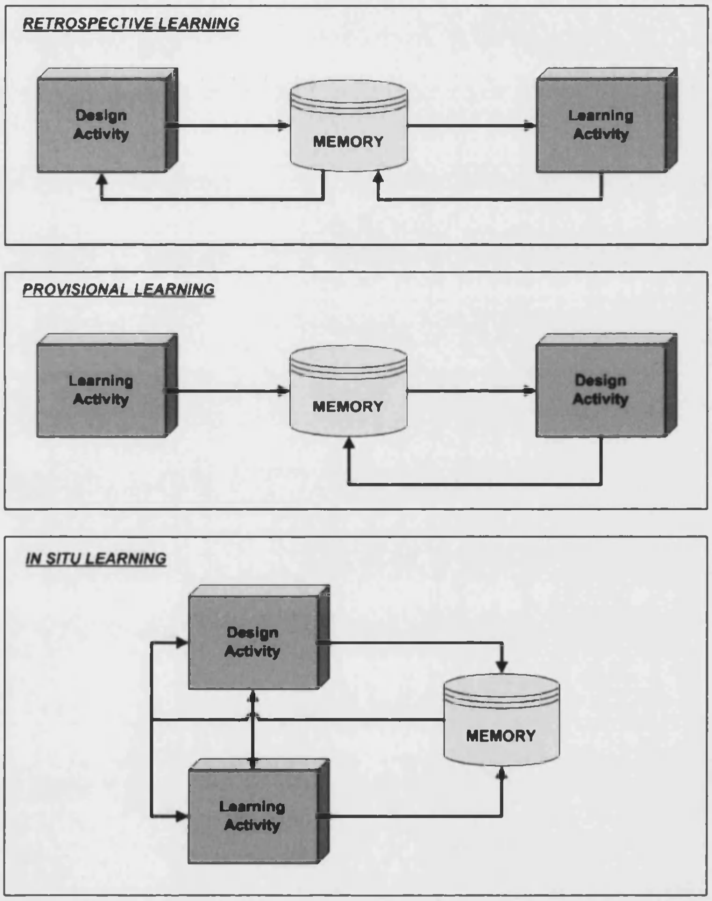


Figure 2.6 *Temporal knowledge interactions between design and learning activities, based on Sim and Duffy (2004)*

Retrospective learning is triggered by the need to learn from past design situations. When designers face a problem they will often look back to lessons learnt from previous cases. Provisional learning happens in anticipation of future design tasks where the designers need up to date information to achieve their goals. This behaviour pattern is particularly visible in new product development situations. Learning as the design activity is taking place or in situ learning is best suited for decision making processes for example where it is important to record the decisions made and the rationale leading to them.

During design reviews, although no detail design activities actually take place, feedback is nonetheless shared between participants leading to a general sense making behaviour and retrospective learning processes. Design management and evaluation, the core activities of a design review, are substantial knowledge creating and decision making situations where participants update their information about the design and discuss the rationale leading to a collaborative plan of actions to take. Design reviews can therefore be considered as an ideal event for *in situ* learning.

4.3. Key factors for sustained knowledge reuse in engineering design activities

In engineering design, an important distinction is often made between product and process knowledge. Although this classification is a partial view of the wider PPRE information framework presented in §3.3, Wallace *et al.* (2005) suggest that KM strategies for designers should focus first on product and process knowledge. Table 2.7 classifies the various types of process and product knowledge which are initially stored in the human memory.

Table 2.7 *Product and process knowledge according to the nature of the knowledge element*

Nature of knowledge	Explicit knowledge	Implicit knowledge	Tacit knowledge
Product knowledge	Explanations about the product (rationale)	Understanding about the product (relationships)	Intuition about the product (insights)
Process knowledge	Explanations about the process (rationale)	Understanding about the process (strategies)	Intuition about the process (insights)

Source: Wallace et al. (2005)

The view on KM presented up until now suggests the existence of key knowledge elements. Clearly, rationale, decisions, and lessons learnt are founding entities on which KM strategies can focus for the effective reuse of design knowledge during the product development process and more specifically the design review process.

4.3.1. Design Rationale

Design rationale in its most general sense "*is an explanation of why an artifact is designed the way it is*" (Lee and Lai 1996). However, this generic definition does not reveal the whole range of issues related to the topic. According to Moran and Carroll (1996b), design rationale can be seen from many different perspectives: it could be the justifications for a designed artifact, a logical representation of the reasons for a designed artifact, a methodology whereby reasons are made explicit throughout the design process, or it could simply relate to the complete historical documentation of a design and its context.

Shipman and McCall (1997) argue that there are three distinctive approaches to design rationale: the argumentation perspective, the documentation perspective and the communication perspective. Argumentation aims to relate the reasoning an individual or a group of designers use to solve a problem. Documentation of the information about the design decision making process is another meaning commonly given to design rationale where descriptive accounts of decisions are captured. Finally, naturally occurring communication between designers, such as conversations, is also a source of design rationale but its capture is more difficult due to its lack of structure and its unpredictability. Based on this classification, design reviews are clearly events where the communication perspective of design rationale needs to be applied. Design rationale research is not new in the engineering world, but the issues that revolve around its capture, representation, and use are still in working progress (Bracewell *et al.* 2004). In their work, Shipman and McCall (1997) conclude that the capture of design rationale from communication with the support of more structured argumentation would help to solve the associated problems of acquisition, retrieval, and usage.

The more generic interrogations outlined by Moran and Carroll (1996a) have been used in the following paragraphs to structure the review of design rationale research.

How much design rationale should be made explicit? Many social and collaborative activities are efficient because everything is not made explicit. Design rationale represented explicitly is important to justify decisions, to predict outcomes based on previous designs, and appropriately reuse past experiences (Brazier *et al.* 1997). The representation schema for design rationale systems can be categorised as argumentation based or descriptive (Regli *et al.* 2000). Argumentation based representations aim at giving a record of the structure of an argumentation; they illustrate the relationships between questions, options, arguments etc. Descriptive representations, which are based on a documentation perspective, give a record of the design steps (who? what? where? when? and why?). More generally, this question also highlights doubts about the applicability of Nonaka and Takeuchi's (1995) knowledge model. Current trends in knowledge management suggest that the way forward lies more in trying to increase the productivity of knowledge workers rather than systematically storing explicit interpretations of their thoughts in a database (Schütt 2003).

Will design rationale techniques be suitable for real development contexts? With their extensive review of design rationale systems, Regli *et al.* (2000) have highlighted two distinctive postures taken by research teams in this area. Process-oriented systems try to map out the history of the design process. Feature-oriented systems on the other hand work on the design space trying to represent how a specific feature of a product can be ensured on the design. This duality recalls the distinction made earlier between process knowledge and product knowledge. Although most existing design rationale systems currently under development are process-oriented, research teams believe that these systems are more suited to capture rationale in the early stages of the design process where design transactions are believed to concentrate more on process information. Feature-oriented systems rely on design and knowledge based rules and will therefore be used in the detail design stages where more product information is believed to be exchanged. Finally, Regli *et al.* (2000) conclude that most of these systems are still in a prototype state and they have yet to make an impact in a real product development context.

Will design rationale change the culture of designing? In a study reported by Karsenty (1996) more than half of the designers' questions during evaluation meetings concern design rationale. The need for efficient methodologies to capture and reuse design rationale is a priority within current KM strategies. However, the approaches proposed so far have quickly shown their limitations; argumentation methods such as gIBIS (Conklin and Begeman 1988), DRL (Lee and Lai 1996), QOC (MacLean *et al.* 1991), and DRCS (Klein 1993) answered less than half of the designers' questions in Karsenty's study. Prusak (2001) argues that for KM strategies to be successful, they will need to follow what has been done by the quality movement; quality is nowadays so embedded in the engineering culture and practices that it has become a natural activity. This goal has sparked a new trend in KM mentality, sometimes referred to as the 3rd Generation or post-Nonaka KM (Schütt 2003), where the attention is drawn on the knowledge productivity of the individual hence regarded as a knowledge worker. From an information system perspective, Karsenty (1996) also underlines the requirement for improved integration between knowledge-oriented technologies and existing engineering design tools.

4.3.2. Decision making

The concept of design rationale is invariably associated with the act of decision making. In engineering design, collaborative decisions are usually taken during meetings; the ones with an impact on the whole project are usually made during design reviews. An organization can effectively be viewed as a network of decision making where compromising and bargaining often take place in spite of well defined standard procedures. Rules and routines are necessary to guide choice behaviour and therefore promote a certain level of consistency and coordination throughout the company, but they must not prevent innovation and creativity (Choo 1998).

> *"Decisions result in commitment to courses of action. Decisions facilitate action taking by defining and elaborating purpose and by allocating and authorizing resources. Although concurrent decision flows generate multiple action streams dispersed in time and location, the institution as a whole must move toward coherent goals, and to do so through strategies that are consistent and coordinated" (Choo 1998).*

In a complete review of current product development processes in the automotive industry, Ward *et al.* (1995) have outlined two distinctive company-wide approaches to decision making in this sector of activity. In a highly structured design process as can be found in the large U.S. automotive companies, decisions are made early in order to freeze the specifications of the product as soon as possible. This decision making process is a typical consequence of a point-based design strategy where the search for the ultimate solution is achieved by an iterative reasoning that moves *"from point to point in the realm of possible designs"* (Ward *et al.* 1995). For engineers working at Toyota or one of their suppliers, the decision process is different and orchestrated through a set-based CE model. In this case, decisions regarding the specifications of the product are delayed so that all parties involved in the product development can propose a set of possible design solutions concerning systems and sub-systems. Instead of making decisions which focus on the improvement of a single solution, set-based design strategies generate decisions which gradually reduce the design space of possible solutions through a rigorous analysis and evaluation of the proposed alternatives. Delaying the decision making in a set-based CE strategy has led Toyota to build better cars faster and hence gain an undeniable competitive edge in the automobile market.

Closer to the practical act of decision making, Badke-Schaub and Gehrlicher (2003) have outlined certain patterns that can be found in design teams. According to the study, a step-sequential decision process is usually more successful than other patterns. Amongst these prescribed processes, three typical procedures have been outlined: *cycles* which include a reiteration of partial sequences of procedure steps, *sequences* which strictly follow theoretical decision making models (clarification, search, analysis, evaluation, decision and control), and *meta-processes* where the decision process is guided by a moderator.

From these previous remarks, it is important to note that the study of design reviews will invariably give insights on the rationale and the decisions leading to courses of action taken by designers and project managers. All the decisions made during a review will therefore be explicitly or implicitly translated into design activities (design definition or design management activities). It will also be interesting to validate and compare the occurrences of the decision patterns with the work reported by Badke-Schaub and Gehrlicher (2003). It is difficult to say whether in the aerospace industry engineering teams follow a point-based or set-based design strategy; it most probably largely depends on the type of partnership existing between the supplier and the aircraft manufacturer. Ward et al. (1995) suggest that certain projects will have fewer constraints and suppliers will therefore propose a large set of alternatives. On the other hand, for minor changes to an existing product the search for alternatives will be highly constrained by the specifications imposed by the client leading to an approach closer to point-based strategies.

4.3.3. Lessons Learnt

In an environment where most of the designer's work involves routine or adaptive design, information concerning past designed products and processes is of great importance to achieve the "new" design within the required time frame at low cost / effort. Lloyd (2000) distinguished three types of experiences used in engineering to transform *"a set of requirements into a reality"*: individual, social and organisational experiences. Individual experience builds the designer's expertise and Marsh (1997) suggests its use lies mainly in *"the exploitation of awareness of alternatives, concerns, work carried out in the past, problem symptoms, etc."* Organisational experience is formalised through company documents such as procedures, product histories, lessons learnt etc. Social experiences are usually constructed in a collaborative environment where experiences are communicated and shared between individuals (Lloyd 2000). There is of course a logical transformation flow between these three types of experiences as shown in Figure 2.7.

***Figure** 2.7 The experience transformation process (Lloyd 2000)*

The transformation process described in figure 2.7 recalls the Nonaka and Takeuchi (1995) organisational knowledge cycle. Current industrial practices suggest that documenting lessons learnt is essential to help design engineers constrain the design space based on past experiences acknowledged by the company. Ward *et al.* (1995) have reported the strategic use of lessons learnt books in set-based design projects at Toyota. These "engineering check sheets" report in detail what can be done from each engineering functional area's point of view (Ward *et al.* 1995). With a similar goal, Airbus has started to develop "lessons learnt cards" where engineers can record the problem description, the context, the proposed solution and the recommendations related to a past company experience. For the purpose of this research, a ***lesson learnt*** *can be defined as a formal explanation of the solution to a problem which occurred in a specific context where new knowledge or an adaptation of existing knowledge was employed.*

Lessons learnt were originally documents exclusively used by in-service departments to report recurring problems on aircraft in service. This methodology is now being expanded across the product life-cycle and design reviews appear to be key collaborative events for the record and dissemination of past design experiences.

4.4. Knowledge-based engineering applications

In the engineering domain, KM is a thriving field of research and the number of knowledge oriented information systems and methodologies generated are vast. Nevertheless, most applications are built using a similar approach. Figure 2.8 represents the typical steps followed by knowledge engineering to develop a knowledge based system (Liebowitz 2001). This knowledge engineering life-cycle model outlines the main development stages of a specific type of artificial intelligence application – Knowledge Based Problem Solving (KBPS) – that requires a rich body of domain specific knowledge (Chandrasekaran *et al.* 1999). Once the knowledge area has been properly defined (problem selection), the knowledge acquisition phase is most probably the most critical aspect of the entire process.

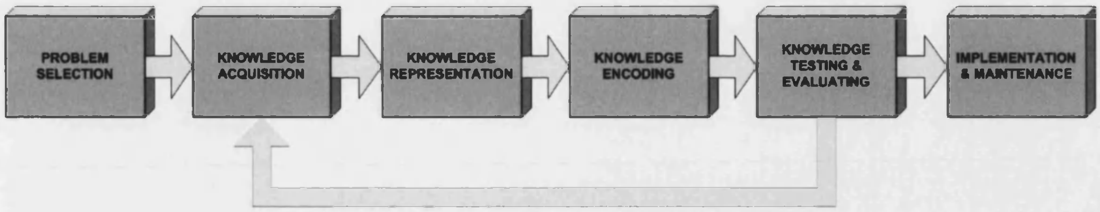


Figure 2.8 *Knowledge engineering life-cycle (Liebowitz 2001)*

A variety of techniques can be used in a knowledge acquisition process. These can be classified in three main categories: natural techniques (interviews, observations and questionnaires), contrived techniques (derived from psychology e.g. role playing, teach back sessions, games, etc.), and modelling techniques (knowledge mapping, structure trees, validation grids, etc.). Natural techniques aim at extracting explicit knowledge from experts, whilst contrived techniques target the implicit or tacit knowledge in their possession. Modelling techniques can also be used as knowledge representation methods, but in the knowledge acquisition phase they are used to validate the knowledge acquired with the experts. Overall, the knowledge acquisition methodologies present noticeable disadvantages: for one, they require personnel dedicated to the task of knowledge acquisition. Then, most methodologies involve the daunting task of transcribing, which is not only very time consuming, but presents no positive interest for the transcribers and therefore seems very costly.

Knowledge representation and encoding is usually based on predefined ontology work. Ontology can be seen as a representation of a vocabulary or a body of knowledge dedicated to a specific topic. Chandrasekaran *et al.* (1999) define ontologies as:

> *"(...) content theories about the sorts of objects, properties of objects, and relations between objects that are possible in a specified domain of knowledge. They provide potential terms for describing our knowledge about the domain."*

The ontological analysis aims at structuring and clarifying the body of knowledge under consideration. Another practical use of ontological building is knowledge sharing between different users linked to a knowledge based system (Smirnov *et al.* 2003). Ontologies are generally visualised as taxonomic trees of conceptualisations representing objects, relations, states, events and processes (Chandrasekaran *et al.* 1999).

Many KM tools have been developed over the past few years for large companies (Barnard and van Beuningen 2004). It has therefore been decided to concentrate on previous and ongoing projects involving Airbus, which have been extensively reviewed by the WISE Consortium (Johnson 2002). MOKA (Stokes 2001), EBoK (Langenberg 2003), PICK

(Robinson *et al.* 2002), and CORMA (Wunram 2000) are four projects that have recently interested knowledge engineering teams at Airbus.

MOKA (Methodology for Knowledge Based Engineering Applications) provides means, a process and software to represent formal and informal engineering knowledge. It was initially a product based approach to engineering knowledge and is currently being developed to deal with processes. The knowledge acquisition part of the MOKA process is facilitated by another KM software, PC PACK (Milton *et al.* 1999). The strength of this approach is to propose informal knowledge models based on a collection of ICARE forms (Illustrations, Constraints, Activities, Rules and Entities). These forms help to structure raw knowledge and progressively validate the model by providing an intuitive communication platform between users and experts. This methodology has been implemented at Airbus.

EBoK (the Engineering Book of Knowledge) is a Lotus Notes database that captures the relevant knowledge to engineers such as lessons learnt and best practices. The EBoK at Airbus is an adaptation of the one originally developed at Chrysler. It is a tool accessed over an Intranet that allows members of a community of practice to collect, structure and share their implicit knowledge in the form of lessons learnt and best practices.

PICK (tools for Process Improvements based on Corporate Knowledge management) aims at developing innovative methods and tools for the effective management of corporate knowledge needed to support process improvement steps, especially for manufacturing processes. It is centred on three major manufacturing companies: SAAB, Daimler Chrysler and Volkswagen.

CORMA (practical methods and tools for corporate Knowledge Management) proposes to develop a KM environment consisting of integrated methods, tools, knowledge representation models, and training materials to support the new product development process in the "Concurrent Enterprises" in the telecommunication sector. The project was redirected to focus on the barriers obstructing the implementation of knowledge management technologies. Three aspects were outlined: the human barrier, the technological barrier, and the organisational barrier.

CHAPTER SUMMARY

Aerospace design mostly involves routine and redesign activities, although high levels of creativity are solicited for the management and control of the product development process of such a complex product. Managing and evaluating the design are therefore key activities when considering design reviews.

The communication processes which take place during design reviews are typically held in a synchronous manner and the essential communication channel – speech – is systematically augmented by a visual stimuli (3D models, sketches, documents, gestures, physical parts etc.). The event falls into the communication category of interface negotiation where engineers working on the same project are invited to share their opinions on predetermined issues. Participants are also required to report on their work as part of this formal problem handling situation.

Spoken information shared during meetings is typically of an unstructured nature, but in the case of design reviews the process is usually structured by textual and pictorial information sources (prerequisites for the review to take place). As described in chapter 1, CE principles induce uncertain information flows between engineering tasks and the need for proper integration of unstructured information in current computer systems is essential for any company wishing to manage and store design information efficiently for further reuse. Research must therefore reflect on the value added to the existing pools of information (human or documentary sources) and understand current information handling behaviours observed in engineering teams.

From an information perspective, the product life-cycle can be represented or modelled according to four typical company-wide dimensions: the Product, the Process, the Resources and the External factors (PPRE). Figure 2.4 proposes an $IDEF_0$ representation of the PPRE information objects related to the design review activity. This information blueprint is a first step towards a generic understanding of the information processes involved in aerospace design reviews.

As stated previously, aerospace engineering deals mainly with redesign activities and has therefore recently focused on knowledge capture and reuse for an improved evaluation and control of their intellectual capital. Knowledge Management (KM) can effectively be viewed as the management of the specific information objects that take part in the company knowledge process. Company knowledge conversion cycles, organizational knowing cycles, and learning processes are some of the theories currently guiding KM practitioners. Based on these conceptual models, design reviews are clearly events where knowledge externalisation and combination processes take place, and where participants have the opportunity to experience retrospective and in situ learning.

From the analysis of the literature related to KM and the specificities of design review activities, milestone meetings are predisposed for substantial knowledge creating and decision making. Participants typically update their information about the design, discuss the rationale leading to a collaborative plan of actions, and share past experiences. Three key elements – rationale, decisions, and lessons learnt – have therefore been singled out for the efficient knowledge oriented recording of information exchanges during design reviews.

Figure 2.9 summarises the different types of design activities that can occur during a design review and relate them to the expected company knowledge process(es) and knowledge element(s).

		Design (D.) review activities									
		D. Evaluation			D. Information sharing			D. Management			
		Decision making	Evaluating	Selecting	Exploring	Identifying	Information gathering	Prioritising	Resolving	Decomposing	Scheduling
Company knowledge process	Sense making		●			●		●		●	
	Knowledge creating				●		●		●		
	Decision making	●		●		●		●		●	●
Key knowledge element	Rationale		●		●	●	●	●	●	●	●
	Decisions	●		●		●		●		●	●
	Lessons learnt		●		●		●		●		

Figure 2.9 *Expected knowledge elements and processes during typical design review activities*

This chapter offers a complete review of the information and communication issues related to the development of an engineering knowledge oriented methodology to support design reviews. Chapter 3 will present detailed conceptualisations of typical meeting mechanisms found in the aerospace engineering domain.

CHAPTER 3

THE STUDY OF ENGINEERING MEETINGS

The previous chapters have highlighted the importance of meetings in the engineering world; the complexity of the tasks to be achieved and the distribution across the globe of stakeholders involved in a project are some of the factors that make meetings indispensable activities to effectively share information and knowledge about the product and its development process.

In this chapter, attention will be drawn to the understanding of meetings through a review of literature on the topic, which has been the focus of a number of different research disciplines. From the findings established by researchers in the engineering domain, the author will propose a unifying view of the various concepts used to describe and analyse design meetings. The resulting pool of concepts will be presented in a parent-child hierarchy. This generic object-oriented model of meeting elements will then be completed by a process-oriented view of design reviews, which illustrates the typical information processes that can occur during this specific type of meeting.

Finally, a study of the role of participants and design artefacts, and an assessment of new meeting technologies will round off the knowledge established by both the object-oriented and the process-oriented representations of a design meeting.

1. REVIEW OF RELATED WORK ON THE STUDY OF MEETINGS

As suggested in the previous chapter, collaborative design activities imply that the participants, regardless of their discipline, need to get together and exchange information for the benefit of the design project. A primary vehicle for such exchange is a meeting. New technologies, especially the evolution of information networks, have expanded the traditional definition of a meeting as a face-to-face situation to a temporally and physically distributed situation where participants do not need to be all at the same place at the same time. Nowadays, the word "meeting" represents a fascinating variety of situations in terms of number of participants, level of structure in the information exchanged, and technologies used to communicate. The aim of this chapter is therefore to gain a theoretical understanding of the underlying elements which constitute a meeting and to present the information processes that can occur in the specific case of a design review, the engineering activity at the heart of the research reported in this thesis.

This section will first review the literature relating to meetings in general. Meetings occur in a wide variety of professional environments, and have thus not only been the subject of study for researchers in the engineering domain, but also for sociology, linguistics, and cognitive science research teams among others. Hence, the next paragraph (§1.1) will provide a brief summarisation of the essential aspects of spoken discourse in the workplace established by sociologists and linguists. The selected findings ultimately highlight the role of speech as the essential vector to explicitly communicate rationale and experience between co-workers. Then, in §1.2, 6 key approaches to meeting analysis in the engineering domain will be explored in detail. A comparative analysis of the various concepts used by these research teams to describe and analyse meetings (§1.3) will help to select the founding elements necessary to construct the object-oriented and process-oriented models of a design meeting. These two perspectives will be presented later in section 2.

1.1. The study of spoken discourse in sociology and linguistics

In sociology and linguistics, studies of verbal transactions between participants of a meeting typically fall into the areas known as discourse and conversation analysis (Blakemore 1988, Schiffrin 1988). The research objectives related to the study of spoken discourse are usually directed towards gaining an understanding of the role of language and its relationship to human behaviour.

A number of case studies have been carried out in order to evaluate sociolinguistic interactions in the workplace. To illustrate what this area of research covers, here are a few topics studied in the Language in the Workplace Project (LWP) (Holmes 2000):

> *"(...) examining particular features or functions of workplace talk, such as directives, small talk, social talk and humour (...), exploring the impact of a particular social variable (gender, ethnicity, professional status ...etc.), examine how relevant it has been in workplace interaction."*

In the specific case of design research and more particularly in the context of this thesis, several topics of investigation from sociology and linguistics have therefore drawn attention. For example, views on how language and thought are linked can bring a strong basis for the study of design rationale through discourse analysis:

> *"Every language provides ways not only of organising sounds, but also thoughts, along with ways of relating theses two disparate phenomena. There are two great benefits. Most obviously, associating thoughts with sounds makes it possible for thoughts to be communicated (...). The other benefit of language lies in the organisation of the thoughts themselves." (Chafe 1998)*

These remarks suggest that there is a close link between how engineers communicate verbally on a project and how their thoughts are sequenced (Dong 2006). Hence, by capturing interactions between designers collaborating on a project, some of the design rationale would be implicitly captured. Making this rationale explicit is the real challenge for any design rationale tool or methodology.

Another important point regarding the study of verbal transactions is the affinity that speech has with past experiences (Boas 1911):

> *"Since the range of personal experiences that language tries to represent is infinite, it seems obvious that an extended classification of experiences must underlie all articulate speech."*

These first observations support the choice of rationale and lessons learnt as key knowledge elements that are made explicit through speech in the context of a meeting.

In practice, the study of spoken discourse requires the recording, transcription, and coding of verbal transactions. It therefore became apparent that during the DTM case studies recording and transcribing the events would be an inevitable step to efficiently monitor verbal transactions for further analysis. Researchers have adapted various forms of transcription coding to their specific needs. Transcription standards do not exist but, in the field of linguistic research, transcripts are encoded in a similar way even if they are not formally standardised. Research produced in this discipline often presents a section dedicated to transcription conventions. This encoding is generally focused on trying to annotate elements of speech that cannot be reproduced by standard written language. Good examples of transcription conventions used in linguistics are detailed in Schiffrin (1987), Heath and Luff (1992), Waldvogel (2001), Poncini (2002), and Vine et al. (2002).

Written transcripts of verbal interactions between participants seem to be an inevitable first step for discourse analysis. Therefore, in order to take full advantage of the DTM case studies, basic transcript conventions and a unique Transcript Coding Scheme (TCS) were developed by the author. The coding elements of the TCS, which will be described later in chapter 4 along with the transcript conventions, stem from the literature review on the topic of meeting analysis in the engineering domain presented in the following sections.

1.2. Review of 6 engineering research projects involving meeting analysis

Across the literature concerning meeting analysis, 6 research teams – the University of Michigan, Project Nick, Projet Eiffel, the Xerox research centre, the Knowledge Media institute (KMi), and the International Computer Science Institute (ICSI) – have been studied in detail based on the relevance, completeness, and rigour the work reported. Most of these research teams include experts from both engineering and human sciences, and have published a number of joint efforts, e.g. Reitmeier *et al.* (1999), Morgan *et al.* (2001).

A detailed analysis of these research programs has been summarised in table 3.1. The "area of research" column shows the engineering discipline at the heart of the research observations, the "research objectives" reviews the overall aim of the research team, and the "research outputs" summarises the achievements reported in the literature.

Overall, certain similarities have been noticed; the common goals driving these projects can be summarised as:

- The creation of collaborative tools to enhance meeting facilities (ICSI, Xerox, KMi, Project Nick).
- Understanding how engineers work / think / operate in a collaborative environment (University of Michigan, Projet Eiffel, Project Nick).
- The facilitation of meetings to avoid failure (Project Nick, KMi, ICSI).

Finally, in table 3.1, the last two columns depict the research environment ("type of meeting") and approach ("research approach") taken by these research teams.

Table 3.1 Presentation of the 6 key approaches to meeting analysis

Research team and related references	Area of research	Research objectives and outputs	Type of meeting	Research approach
University of Michigan Olson *et al.* (1993) ; Bekker *et al.* (1995) ; Olson *et al.* (1996); Reitmeier *et al.* (1999)	Computer science & technologies (case studies at MCC and Andersen consulting)	**Objectives:** outline content structure in design meetings, verify if design rationale schemes are useful as a process aid for designers, develop methods to support design. **Outputs:** description of the sequential structure of design meetings, coding scheme based on design rationale activities.	Software design, early stages of the design process, exploration of the requirements	Naturalistic observation and computational research (action research)
Project Nick Cook *et al.* (1987); Ellis *et al.* (1989); Ellis *et al.* (1991)	Computer science & technologies (case studies at MCC)	**Objectives:** study of meeting failure, develop new meeting technologies, understand dynamics of meetings, improving meetings. **Outputs:** categorisation of software design meetings, use of meeting tools, pre-meeting/post-meeting/during-meeting aids.	Software design, early stages of the design process, exploration of the requirements	Naturalistic observation and computational research (action research)
Xerox Elrod *et al.* (1992); Minneman and Harrison (1993); Pedersen *et al.* (1993); Minneman *et al.* (1995); Moran *et al.* (1997)	Computer science & technologies	**Objectives:** produce accurate records of meetings, evaluate computational tools to support collaborative work, describe capture and salvage tools for meetings. **Outputs:** practical definition of "salvaging" meetings, design implications of salvaging.	Peer review meetings, assessment of new ideas for intellectual capitalization	Naturalistic observation and computational research (action research)
Projet EIFFEL Robillard *et al.* (1998); D'Astous (1999); D'Astous *et al.* (2000); D'Astous *et al.* (2001)	Computer engineering, cognitive science	**Objectives:** define collaborative tools for designers, research on collaborative design activities. **Outputs:** development of methodologies for the researcher and for the user based on 16 Nationwide projects and 4 international co-operations.	Technical Review Meetings in software design, decision making.	Protocol analysis
KMi Sierhuis and Selvin (1996); Dzbor and Zdrahal (2001); Selvin *et al.* (2001); Conklin (2003)	Computer science & technologies, Knowledge Management	**Objectives:** map complex thinking into structured analytical maps, capturing meeting rationale through IBIS grammar. **Outputs:** Compendium and QuestMap software.	Various types of meetings in business and government context	Prescriptive and computational research (action research)
ICSI Morgan *et al.* (2001); Shriberg *et al.* (2001); Janin *et al.* (2003); Morgan *et al.* (2003)	Computer science & technologies	**Objectives:** automatically capture contents of meetings, develop a system that passively captures and analyses meeting discourse and becomes an active participant. **Outputs:** entity recogniser, topic tracker, question identifier, multi-speaker and independent speech recognition.	Research meetings in speech recognition and natural language processing	Naturalistic observation and computational research (action research)

The "meeting type" column shows that most of the teams have studied meetings in their domain of research; computer science or software design. Only the KMi team used a different area of study (consulting company on governmental policy making). A majority of the case studies (University of Michigan, Porject Nick, Xerox) were directed towards meetings held in the initial stages of the design process (prior to the specification of the requirements) where exploration and brainstorming are key activities. Closer to the DTM case studies, projet EIFFEL studied Technical Review Meetings in the software design domain, which emphasise on problem solving and decision making. These meetings differ however from aerospace design reviews in many aspects, e.g. they are not guided by international standards, they do not involve multi-disciplinary teams (only software design engineers), they are relatively short (1 ½ hrs), etc.

The "research approach" column indicates the various methodologies used by the 6 research teams to complete their studies. Because of the focus on the development of software tools to support collaborative activities, most have concentrated their efforts on a computational approach including variable levels of prescriptive research techniques to validate the prototypes. Nevertheless, most of the teams have spent some time observing meetings in a naturalistic approach prior to the development of computer tools, especially in the case of Xerox and ICSI where the research environment and objectives facilitated this type of methodology. Protocol analysis has also been a source of data for some of the teams, i.e. University of Michigan and Projet EIFFEL. Because of the objectives of the research and the nature of the case studies, the DTM approach described in chapter 1 (§2.2) is slightly different from the one adopted by these previous projects and is strongly based on a naturalistic methodology; here, the development of software tools to support design reviews is not a priority.

1.3. Analysis of meeting concepts with relationship matrices

Five of the research teams presented in §1.2 (University of Michigan, Project Nick, Projet Eiffel, Xerox and KMi) published detailed methodologies for meeting analysis. These are based on analysing aspects of a meeting through pre-defined meeting concepts and sub-concepts. Nevertheless the terminology used by the researchers for these analyses is wide-ranging and has considerable redundancy. It therefore seemed interesting to verify which terms were used for identical concepts and which ones might be useful to keep for an original classification for the development of a new engineering focused approach.

In order to examine the similarities and differences in the use of this range of meeting analysis concepts, two relationship matrices have been built. The analysis of these matrices has led to the construction of specific representations of the pool of concepts related to meeting analysis: an object-oriented hierarchy of meeting elements and a process-oriented model of aerospace design reviews, both detailed in section 2. These models will then serve as a basis for the elaboration of a number of meeting analysis tools, including a unique Transcript Coding Scheme (TCS), presented in chapter 4.

1.3.1. How to read the matrices?

The first matrix, matrix A, compares high level concepts and related sub-concepts found in each one of the five methodologies. Because of the size of this comparative matrix (54x54), it has been divided here into sections as illustrated in figure 3.1. Therefore, figures 3.2a), 3.2b), and 3.2c) respectively show the top left, top right, and bottom right sections of matrix A. The bottom left section has been left out because the matrix is symmetrical and the results are thus identical to the ones shown in the top right section.

A second matrix, matrix B, has been produced to analyse the terminology used to describe the sub-concept behind the word "speech activity" used in the literature reviewed for Project Nick, Projet Eiffel, and the University of Michigan. This matrix (size 27x27) is shown in full in figure 3.3, and presents the same symmetrical properties as matrix A.

The entries in the two matrices have been divided into high-level concepts X_j and, Y_l and, in the case of matrix A, into sub-concepts X^i_j or Y^k_l. These concepts and sub-concepts have been assimilated to sets, and relationships between them are defined by specific rules and logical operators from the theory of sets.

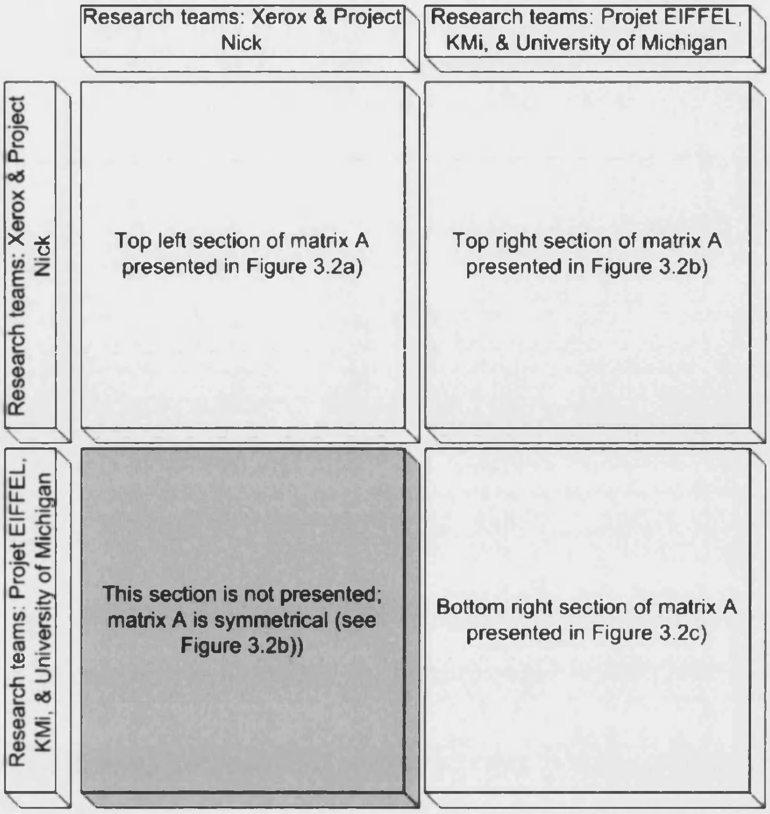


***Figure 3.1** Layout of matrix A in figures 3.2a), b), & c)*

Using the theory of sets, the following formulas dictate the properties of the matrices and how the relationships must be read (X_j, X_j^i, Y_l, Y_l^k are referenced in figure 3.2a and 3.3):

$$\forall j,l \in \mathbb{N}, \forall j,l \in [1,...,13]\ for\ matrix\ A, \forall j,l \in [1,...,27]\ for\ matrix\ B$$

$$\forall \Omega_j, \Omega_l \subset \mathbb{N}, \forall i \in \Omega_j, \forall k \in \Omega_l$$

$$\Omega_j\ set\ of\ subconcepts\ contained\ in\ X_j,\ and\ \Omega_l\ set\ of\ subconcepts\ contained\ in\ Y_l$$

$$Properties:$$

$$(1) \Leftrightarrow \begin{Bmatrix} X_j^i \subseteq X_j \\ Y_l^k \subseteq Y_l \end{Bmatrix}$$

$$(2) \Leftrightarrow if\ j = l\ then \begin{Bmatrix} \Omega_j \equiv \Omega_l \\ X_j \equiv Y_l \end{Bmatrix}$$

$$(3) \Leftrightarrow if \begin{Bmatrix} j = l \\ i = k \end{Bmatrix} then \begin{Bmatrix} \Omega_j \equiv \Omega_l \\ X_j \equiv Y_l \\ X_j^i \equiv Y_l^k \end{Bmatrix} (for\ matrix\ A)$$

$$Relationship\ rules:$$

$$for\ matrix\ A: \begin{Bmatrix} \bullet_{(i,k)} \equiv \{X_j^i \subseteq Y_l^k\}\ or \{Y_l^k \subseteq X_j^i\} \\ \circ_{(i,k)} \equiv \{X_j^i \cap Y_l^k \subsetneq \{\varnothing\}\} \end{Bmatrix}, for\ matrix\ B: \begin{Bmatrix} \bullet_{(j,l)} \equiv \{X_j \subseteq Y_l\}\ or \{Y_l \subseteq X_j\} \\ \circ_{(j,l)} \equiv \{X_j \cap Y_l \subsetneq \{\varnothing\}\} \end{Bmatrix}$$

In simple words:

- A relationship marked by a full circle in the matrix means that the definitions of both sub-concepts match.
- An empty circle means that they have a partial match in their definitions.
- Concept definitions match or partially match when all their sub-concepts match or partially match (in the case of matrix A).

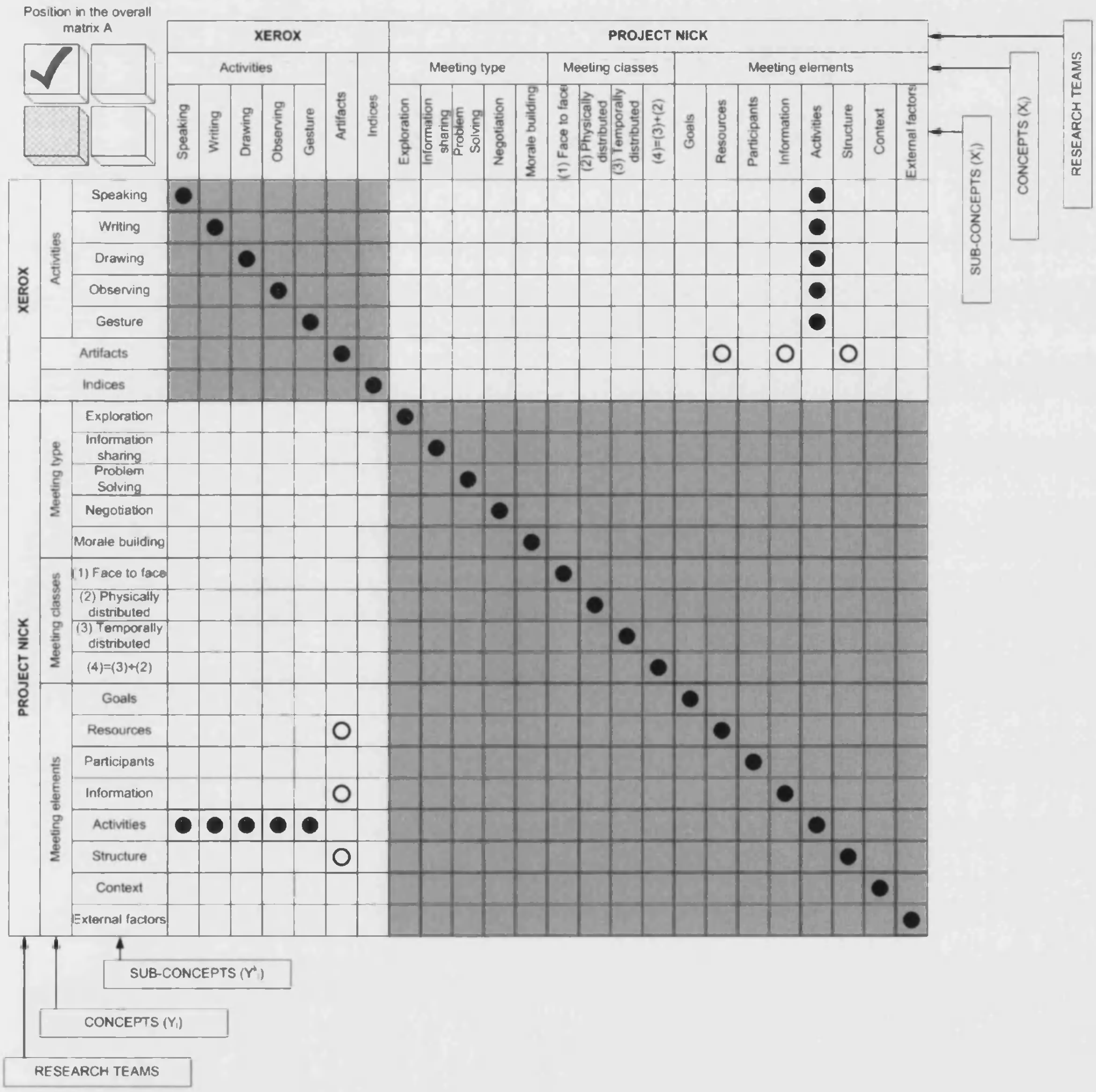


Figure 3.2a) *Top left section of matrix A comparing meeting analysis concepts used by different research teams*

			PROJET EIFFEL												KMI							UNIVERSITY OF MICHIGAN										
			Intervention coding					Exchange type				Sequence			Questions		Ideas		Arguments			Meeting activities										
Position in the overall matrix A			Speaker ID	Activity	Subject	Criteria of form	Criteria of content	Cognitive synchronization	Review	Conflict resolution	Alternative elaboration	Nested exchanges	Rule A	Rule B	Problem	Issue	Solution	Explanation	Evidence	Facts	Viewpoints	Issue	Alternative	Criterion	Project management	Meeting management	Summary	Clarification	Digression	Goal	Walkthrough	Other
XEROX	Activities	Speaking		●	O	O	O	O	O	O	O	O			O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		Writing																					●						●			
		Drawing																					●						●			
		Observing																					●						●			
		Gesture																														
	Artifacts																		O	O												
	Indices		O																													
PROJECT NICK	Meeting type	Exploration						O	O		O																					
		Information sharing						●	O																							
		Problem solving								O																						
		Negotiation							O	O	O																					
		Morale building																														
	Meeting classes	(1) Face to face																														
		(2) Physically distributed																														
		(3) Temporally distributed																														
		(4)=(3)+(2)																														
	Meeting elements	Goals			O																									●		
		Resources																														
		Participants	O																													
		Information				O	O								O	O	O	O	O	O	O											
		Activities		O											O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		Structure			O																											
		Context																														
		External factors																														

Figure 3.2b) *Top right section of matrix A comparing meeting analysis concepts used by different research teams*

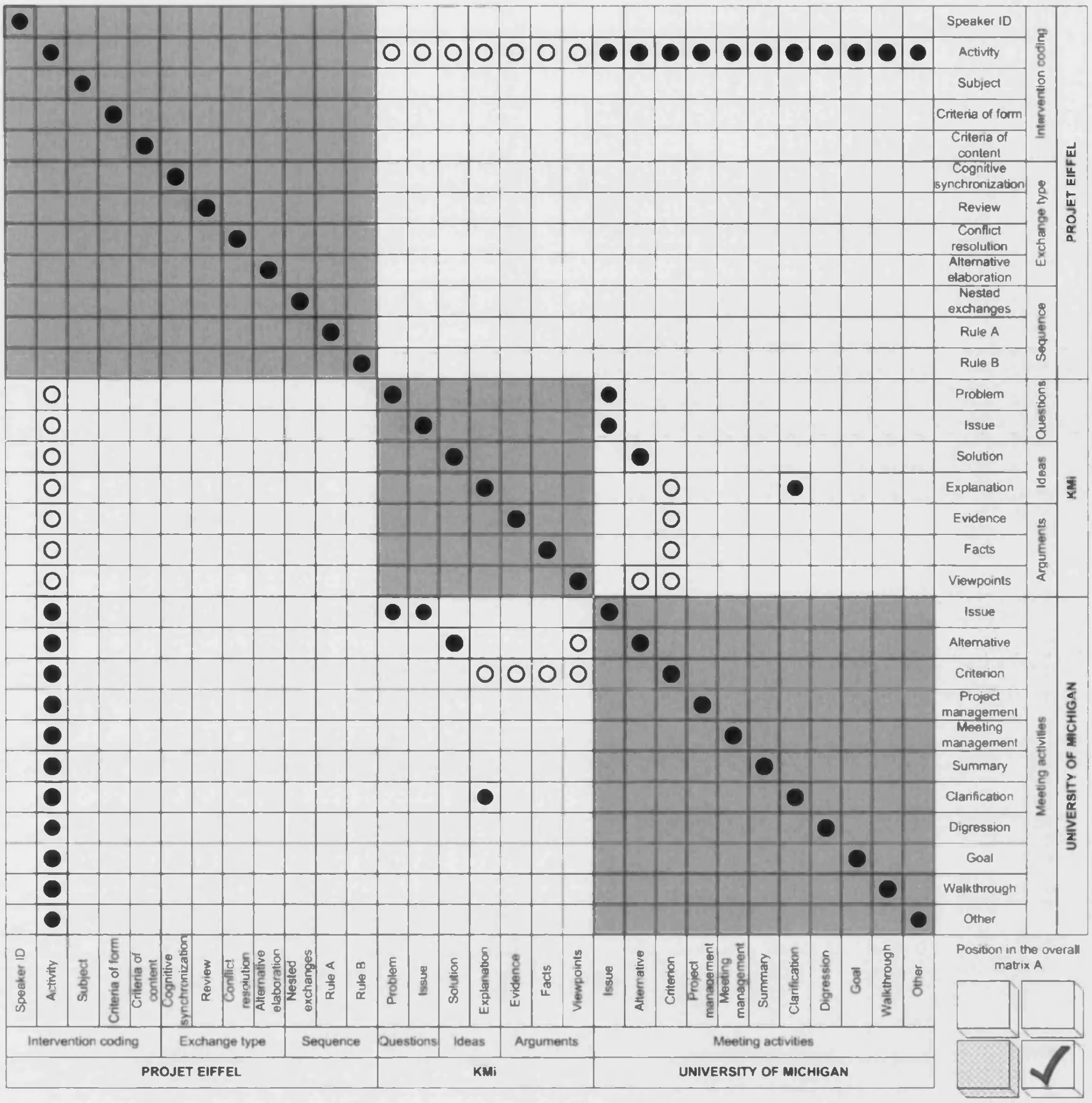


Figure 3.2c) *Bottom right section of matrix A comparing meeting analysis concepts used by different research teams*

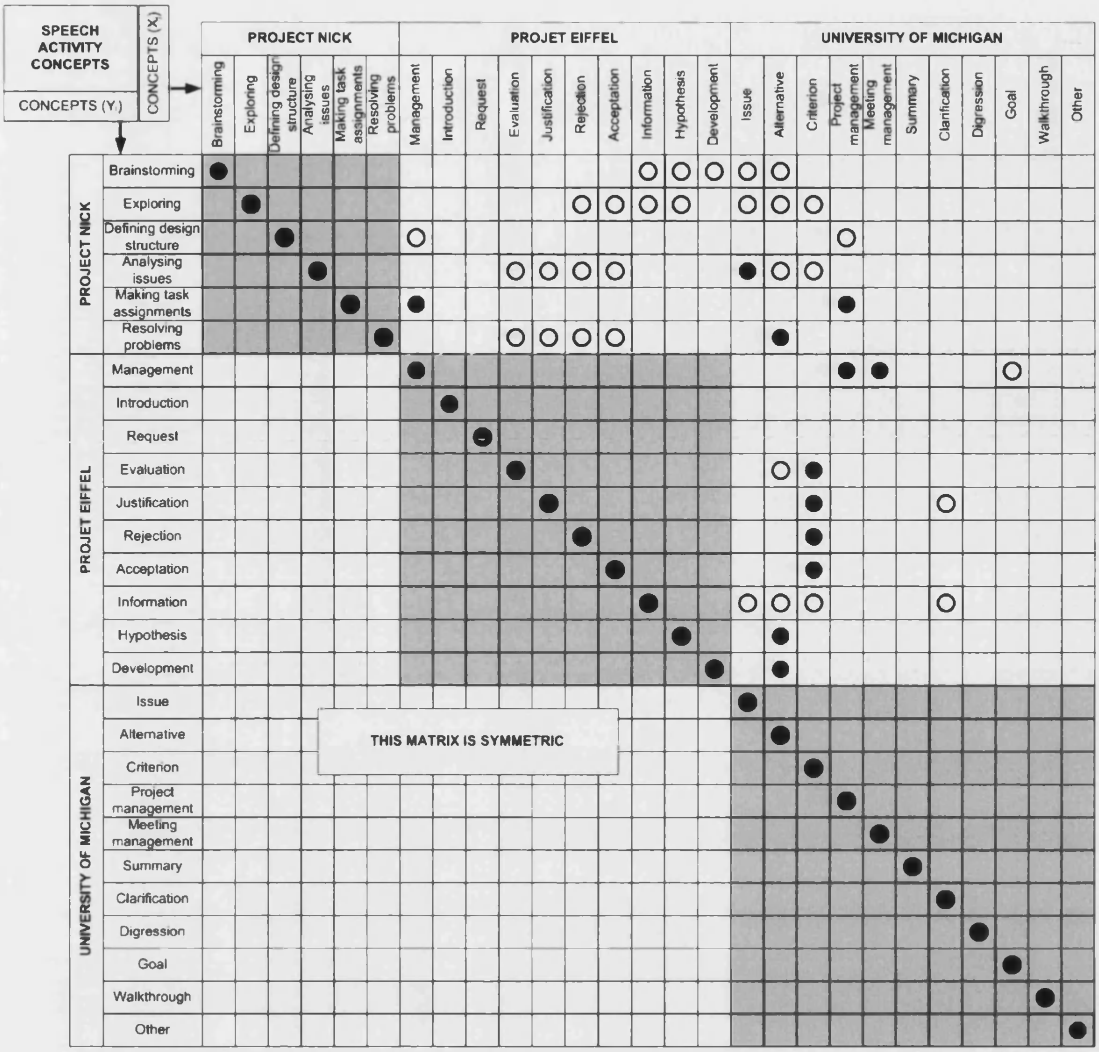


Figure 3.3 Matrix B comparing "speech activity" concepts

The analysis of these two matrices has been drawn to the extremes: concepts with a high number of exact and partial matches or those with no matches at all. Two general remarks can be made about the meaning behind the high/low match (partial or exact) between these concepts:

- No match can mean two things: the concept is unique and characterises meetings in an original way, or the concept is not of use to meeting analysis in the context of this research.
- A high number of partial matches can mean that the concept is a very generic definition (high level concept), but can also mean that it has been ill-defined.

- A high number of exact matches mean that the concept is present with a similar meaning in other methodologies; in this case a unique terminology has to be chosen.

1.3.2. Matrix A showing terminology similarities between key meeting analysis concepts

The matrix A, presented in figures 3.2 (a, b, & c), presents relationships between terminologies used in each one of the 5 meeting analysis methodologies encountered.

From Matrix A, the following remarks can be made:

- The word "activity(ies)" has often been used to describe what the author will refer to as "communication elements" for the DTM case studies. The related sub-concepts are often "speech activities" and these have been analysed more specifically in the second matrix (matrix B).
- The general denomination "meeting elements" (Project Nick) has been chosen to define all the entities that can be used to analyse a meeting. These meeting elements therefore represent the pool of concepts necessary to analyse a meeting and can be further divided into two categories: those linked to the content of a meeting, and the ones defining the structure of a meeting.

From these preliminary observations, the following concepts and sub-concepts have been selected for integration (with a possible adaptation) in the two original representations of meeting elements presented in section 2: speaking, writing, drawing, observing, gesture, artefacts, meeting classes, face to face, physically distributed, temporally distributed, meeting elements, information, intervention coding, speaker ID, subject, exchange type, arguments, evidence, facts, issue, clarification.

1.3.3. Matrix B showing terminology similarities between speech activity concepts

Matrix B (figure 3.3) relating "speech activity" terminologies found in 3 of the 6 analysis methodologies reviewed previously (Project Nick, Projet Eiffel, and University of Michigan), was created to give a better insight into the diversity of speech types used when analysing meeting discourse. This concept is important to investigate as it is a founding element of the TCS, which will be presented in chapter 4.

The results from this matrix are quite different from the previous one. Overall, there is a fairly high number of concepts that match each other; the different research teams have used different vocabularies to express similar concepts or ideas. The teams have studied different domains (software or mechanical engineering) and therefore the difference in the terminology used might quite simply be linked to the environment.

Another remark has to be made on the type of words used by these different research projects to analyse "speech units"; Project Nick has used verbs in their gerundial form (brainstorming, exploring, defining, analysing, making and resolving) whereas the two other research groups have used nouns. When analysing a transcript of a conversation, one needs to cut it up into speech segments or units, and the smallest useful unit observed in all 3 studies was a participant's intervention. Consequently, units of speech or interventions will be of different types and the most appropriate terminology to define them would be nouns (a statement, a question ...etc.). On the other hand it is also important to cluster these primary units into a larger sequence of interactions to have a better understanding of the purpose of the evolving exchanges in a conversation. It seems more appropriate to define these exchanges or clustered interventions by a set of types using verbs in their gerundial form.

By analysing Matrix B it is obvious that Project Nick has looked at exchanges whereas project Eiffel and University of Michigan have both concentrated on a smaller unit of speech. This is reflected by a high number of partial matches between Project Nick and the two others, and a comparatively higher number of exact matches between the terminologies used by University of Michigan and project Eiffel. The notions of "intervention" and "exchange" are crucial concepts for the coding of transcripts and will therefore be refined in the next section (§2.1).

2. CHARACTERISING DESIGN MEETINGS

From the study of matrices A and B, a number of concepts have been chosen to describe and ultimately analyse design meetings. Of course, the "type of meeting" and the "research approach" (see table 3.1) used by the research teams reviewed in the previous section also implicitly influenced the final choice. Overall, projet EIFFEL described a type of meeting close to aerospace design reviews and Project Nick used a holistic research methodology to understand the nature of meetings. The pool of concepts selected to characterise design meetings for the purposes of the DTM research has therefore been strongly influenced by these two research project.

To obtain a complete conceptualisation of the constitutive elements of a meeting and the typical processes involved in the activity, two distinctive modelling approaches have been adopted. The first one uses an object-oriented hierarchy of "meeting elements" (Cook *et al.*

1987) in the form of a tree in order to describe what constitutes a design meeting. The second approach is based on an $IDEF_0$ type model (NIST 1993) where typical information processing mechanisms can be viewed from the specific perspective of an aerospace design review.

These two theoretical knowledge representations of the meeting activity recall the distinctions proposed in chapter 2 between product knowledge and process knowledge; a meeting can be seen as both an object and a process. The first objective of these two models is to attain a conceptual level of understanding of the meeting phenomenon and more specifically of an aerospace design review. The conceptualisation will also provide a coherent framework to develop tools for aerospace design review analysis, notably the TCS, which will be presented in chapter 4 and used to analyse design review case studies in chapter 5.

2.1. An object-oriented design meeting model

Transcribing discourse in written words is a way to encode a certain event, in this case a meeting. But this first step does not meet the requirements for the transcript to be understood and processed. The transcript needs to be further formalised so that the information output of the encoding meets the information structure requirements of a meeting model.

The first step to produce a formal model of a meeting is to try and order hierarchically the pool of concepts, which have a systematic influence in the analysis of the information generated. Figure 3.4 illustrates a breakdown of the entity "meeting elements" into a parent-child hierarchy of entities with four levels of specialisation. It is based on an entity-attribute relationship model, as defined in the EXPRESS language (ISO 10303-11:1994) for example. Each "entity" possesses a certain number of "attributes" which can be further detailed by "type" or "value". The meeting elements entity can be considered as a super-entity or scheme. The hierarchy is complemented by tables 3.2 and 3.3 that define all the entities and related attributes used in figure 3.4. In table 3.2, the entities are ordered by level of specialisation, level 0 containing the super-entity meeting elements and level 1 the two super-entities, "structure elements" and "content elements". Table 3.3 defines the attributes associated to each entity in the meeting elements hierarchy by proposing either a definition, or simply the list of representative values or types.

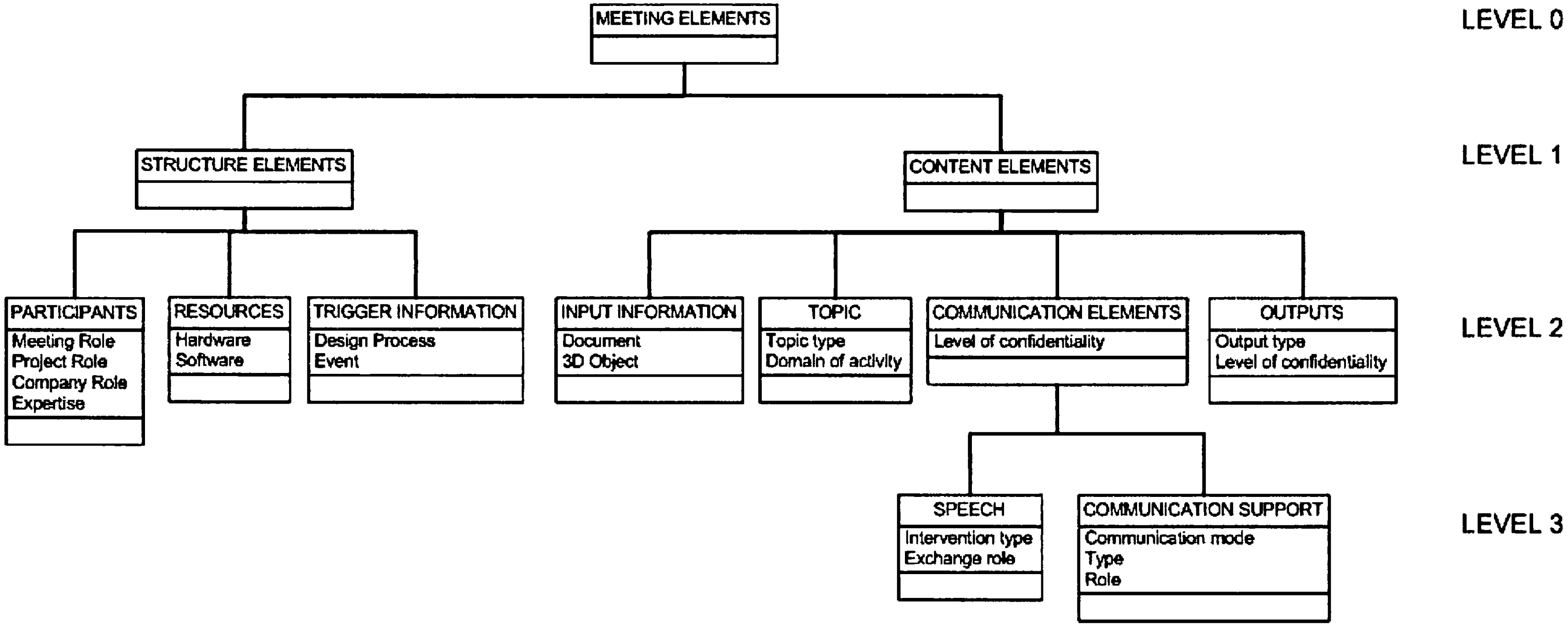


Figure 3.4 *The meeting elements hierarchy (entities in caps and attributes in lower case)*

Table 3.2 Description of the entities in the meeting elements hierarchy

Level of specialisation	Entity	Description and related reference
Level 0	Meeting elements	The observable elements which constitute a meeting in terms of structure and content (Cook *et al.* 1987).
Level 1	Structure elements	The word "structure" is used in the sense of giving form to; hence structure elements are the entities on which the meeting has been built (notion of context and structure used by Cook *et al.* (1987)).
	Content elements	Entities belonging to this category will help characterise the nature and the content of the information transactions that take place during a meeting.
Level 2	Participants	Through their individual profile, their expertise and their expected role for the meeting (chair, secretary, consultant ... etc.) the participants have a crucial impact on the way the meeting evolves (Cook *et al.* 1987).
	Resources	They are the meeting facilities, the objects used during meetings, but with no impact on content. Resources can be divided into hardware resources (chairs, tables, computer and meeting technology hardware) and software resources, which help run the meeting (Cook *et al.* 1987; Moran *et al.* 1997).
	Input information	Information prepared before the meeting which plays a role in the development of the meeting (agenda, procedure documents, drawings ... etc.)
	Trigger information	A piece of information or event, which initiated the meeting (a milestone in the design process or an unexpected event for example).
	Topic	This entity is at the centre of the content of a meeting, it defines the topic of the on going information exchanges (Robillard *et al.* 1998). A change of topic will be initiated by a new intervention or artefact and will set a new exchange between participants. Of course there are an infinite number of possible topics that can appear during a meeting, but in the case of the DTM project it should be possible to classify them in generic categories related to the domain of activity.
	Communication elements	These refer to the means by which the information is conveyed between the participants (communication mode); the possibilities are linked to human communication capabilities: speech, text, sketch and gesture (Moran *et al.* 1997)
	Outputs	Artefacts (Moran *et al.* 1997), decisions and opinions generated from the meeting process.
Level 3	Speech	Main communication mode during a meeting. Most of the transcript analysis methodologies have focused on the study of this element (Cook *et al.* 1987; Olson *et al.* 1993; Robillard *et al.* 1998). For the purpose of this research speech will be divided into interventions, which will constitute the elementary unit for spoken discourse analysis. Interventions will then be grouped in exchanges (Robillard *et al.* 1998).
	Communication support	The other communication modes (pictorial, text and gesture) are considered to support the speech activity (Bekker *et al.* 1995) Therefore they can be classified according to the information type they are conveying and their role in the conversation.

Table 3.3 *Description of the related attributes in the meeting elements hierarchy*

Entity	Attributes	Description or associated types / values
Participants	Meeting role	Chair, secretary, facilitator, presenter, participant.
	Project role	Engineer, project manager, etc.
	Company role	Team leader, chief engineer, etc.
	Expertise	Relates to the domain of expertise: aircraft structure, procurement etc.
Resources	Hardware	Facilities used in the meeting room: chairs, computers, microphone etc.
	Software	Software controlling the progress of the meeting; videoconferencing etc.
Input information	Document	Agenda, reports, drawings etc.
	3D object	CAD models, Digital Mock-Ups, Physical objects (parts or assemblies)
Trigger information	Design process	Milestones or predefined meetings in the project management plan.
	Event	Unexpected or requested event.
Topic	Topic type	Predefined, unexpected or derived.
	Domain of activity	Related domain of competence within the company and partners: design, manufacturing, production, management, in service, marketing etc.
Communication elements	Level of confidentiality	Personal, internal or public
Outputs	Output type	Type of artefact recorded from the meeting, such as: documents, sketches, drawings, objects, written notes, annotations through meeting facility tools, audio/ video recordings of the meeting...etc.
	Level of confidentiality	Personal, internal or public
Speech	Intervention type	Statement, Question, Answer or Feeling/Emotion (Conklin 2003)
	Exchange role	Exploring, Resolving problems, Managing, Evaluating, Debating, Digressing, Informing, Clarifying, or Decision making.
Communication support	Communication mode	Textual, pictorial or gesture.
	Type	Type of artefact or behaviour used to support conversation during meetings, such as: presentation slides, documents, sketches, drawings, objects, written notes, annotations, meeting management techniques, gesture types etc.
	Role	The role of communication support elements can be broadly categorised as an aid to the externalisation of mental images and ideas or a support for cognitive processing (Moran and Carroll 1996b).

Figure 3.4, table 3.2, and table 3.3 can be considered as founding elements for the development of more complete and standardised modelling techniques such as ontological work or object-oriented programming solutions. However, it is not the intent of this research to further develop this "meeting elements" model; more work would be required to define relations, rules, events, and states for each one of the entities and related attributes. The underlying goal of the simple classification scheme illustrated in figure 3.4 is to define a unifying vocabulary for the purpose of experimental analyses of design meetings.

It is important to note that the study of the "speech" entity is the focus point of most transcript analysis methodologies. Speech can be divided like a written language into words or even letters. As suggested in §1.3.3, it is of greater interest to sub-divide a speech activity into interventions, which will constitute the elementary unit for the spoken discourse analysis. Interventions can then be grouped in exchanges. This decomposition of a conversation is based on Robillard *et al.* (1998):

> *An intervention is a statement made by a single speaker (...) a series of interventions made by different speakers is called an exchange.*

Of course, in certain specific cases different interventions made by a single speaker can be considered as an exchange (e.g. in the case of a presentation). There are different types of possible interventions and exchanges in a design meeting; from the literature reviewed in §1.3.3, here are the preliminary lists of intervention types and exchange roles, both attributes of the "speech" entity, which could be encountered during a design meeting:

- Intervention types: statement, question, answer, feeling. These basic units could be highlighted by specific discourse markers. Schiffrin (1987) identifies distinctive discourse markers such as: 'well', 'now', 'so', 'but', 'oh', 'because' etc.
- Exchange roles: exploring, resolving problems, managing, evaluating, debating, digressing (which can involve the making of informal contacts between participants), informing (in the sense of reporting or delegating), clarifying and decision making.

2.2. A process model of aerospace design review activities

In an organisational context there are many different types of meetings that take place. Of course, the terminology used to define them varies according to the company and in some cases the departments concerned. During the course of his study on the implementation of new business processes in a large aerospace company, O'Sullivan (2000) reported 5 types of formal internal meetings and another 5 types when suppliers were involved. These findings are interesting examples of formal meetings in the aerospace industry and have been summarised in table 3.4.

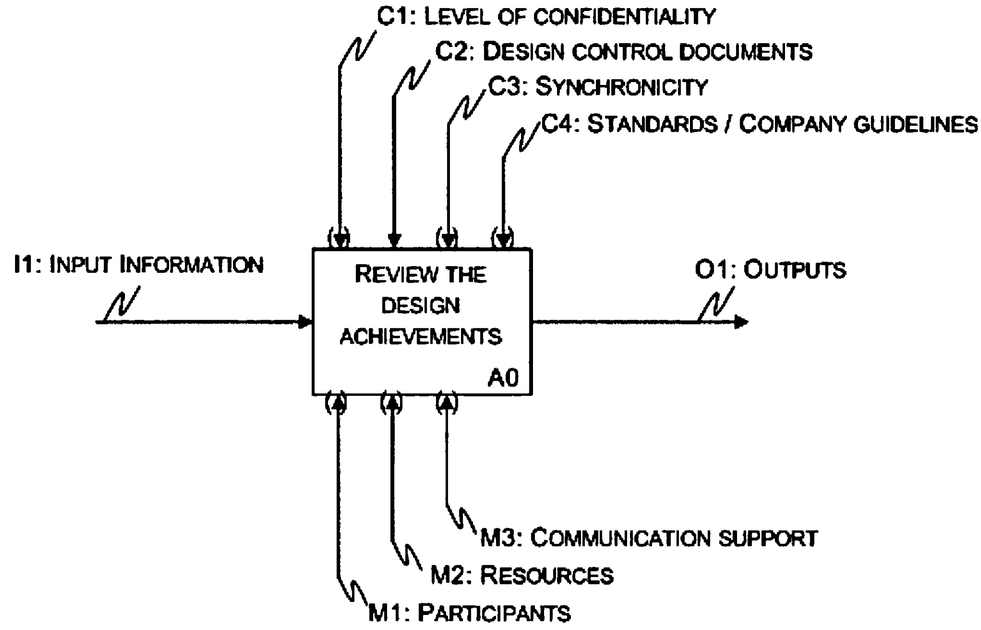
Table 3.4 *Types of formal meetings encountered by O'Sullivan (2000)*

Type of meeting	**Internal (I) or External (E)**	**Purpose**
Weekly technical reviews	E	Coordinate and monitor progress toward achieving the deliverables.
Weekly project reviews	I	Progress update of design work, individual suppliers, actions to be carried out.
Weekly program reviews	I	Progress update of overall program, each department, business case, overall risk management.
Bi-weekly key issues meetings	E	Bring key issues or risk items to the attention of the project management team of the aircraft manufacturer. Resolve management issues.
Bi-weekly integrated development test team	I	Coordinate all development testing in one group with emphasis on avionics.
Monthly executive-level reviews	E	Progress report, key issues for senior management.
Monthly executive reviews	I	Progress report, key issues for the company's senior management.
Advisory council reviews	I	Incorporate user needs by involving practicing pilots to review progress on overall program and design work.
Quarterly all partner reviews	E	Progress reports by each major department and supplier.
Phase reviews	E	Progress report in relation to technical and program requirements. Scheduled according to the product development process.

Source: O'Sullivan (2000).

Whether internal to the company or involving external participants, table 3.4 illustrates how a "review" is a terminology which can represent a variety of events even within the same company. For this reason, the process model developed here is dedicated to a specific type of review: the formal design review as defined in chapter 1, which matches the term "phase review" in table 3.4. The DTM case studies, described later on in chapter 4, are all examples of this type of meeting.

As suggested in chapter 2, a meeting can be seen as an activity where information elements are processed and transformed. To complete the characterization of design meetings, figure 3.5 presents an $IDEF_0$ parent diagram (NIST 1993) of an aerospace design review process.



Context: the aircraft industry control process dedicated to research and technology, new developments, continuing developments, and in-service.

Viewpoint: participants of the design review.

Purpose: produce a structured model of an aerospace design review activity and its typical sub-activities including examples of the information elements and objects involved in the process.

Figure 3.5 *The IDEF$_0$ parent diagram of an aerospace design review process*

The goal of this modelling approach is to propose a structured and generic view of the information processing dimension in the case of an aerospace design review. The parent diagram (figure 3.5) and the detail diagram (figure 3.6) contain information elements from the initial design review information blueprint presented in chapter 2, objects from the meeting elements hierarchy and also integrate some meeting concepts left out by the object-oriented model.

A concept that was left out in the meeting elements hierarchy, and now appears in figure 3.5, is the notion of synchronicity. Formal design reviews are generally held in a synchronous manner and face-to-face. Nevertheless, the development of new information technologies (chat rooms, instant messaging, online forums etc.) combined with new Stage-Gate processes where certain decisions are delayed in time (see chapter 1, §1.2.3) have enabled certain design review activities to be held in an asynchronous manner. A design review can sometimes be divided in sub-meetings to address specific issues or use videoconferencing technologies to connect remote teams; this has an impact on the resources involved and the location of the meeting can therefore be unique or multiple locations.

Figure 3.5 depicts the overall constraints or controls (C1 to C4), the mechanisms or resources (M1 to M3) and the inputs (I1) / outputs (O1) involved in a formal design review activity ("review the design achievements (A0)"). "Level of confidentiality" (C1), "synchronicity" (C3), and "standards and company guidelines" (C4) are elements which control the overall activities involved in a design review. In the same way, all the mechanisms listed: "participants" (M1), "resources" (M2) and "communication support" (M3) are valid for all design review activities. Most of these elements have been defined in §2.1.

The "input information" (I1), "outputs" (O1), and "design control documents" (C2), however, are generic terms which enclose a variety of information elements. Based on the literature reviewed in chapter 1 and 2, and especially the work proposed by Sim and Duffy (2003), the generic design activity represented by the box A0 was further decomposed into three sub-activities: "share information about the design" (A1), "evaluate the design" (A2) and "manage the design" (A3). The information sharing activity is specific to design reviews and is therefore not part of the classification proposed by Sim and Duffy (2003). In the context of a design review, design evaluation and management involve a number of sub activities presented in chapter 2 (figure 2.9) but these are not relevant for the generic modelling approach adopted here. The $IDEF_0$ detail diagram in figure 3.6 illustrates the relationships between the three main design activities (A1, A2, and A3) and their surrounding information elements, which constitute a design review.

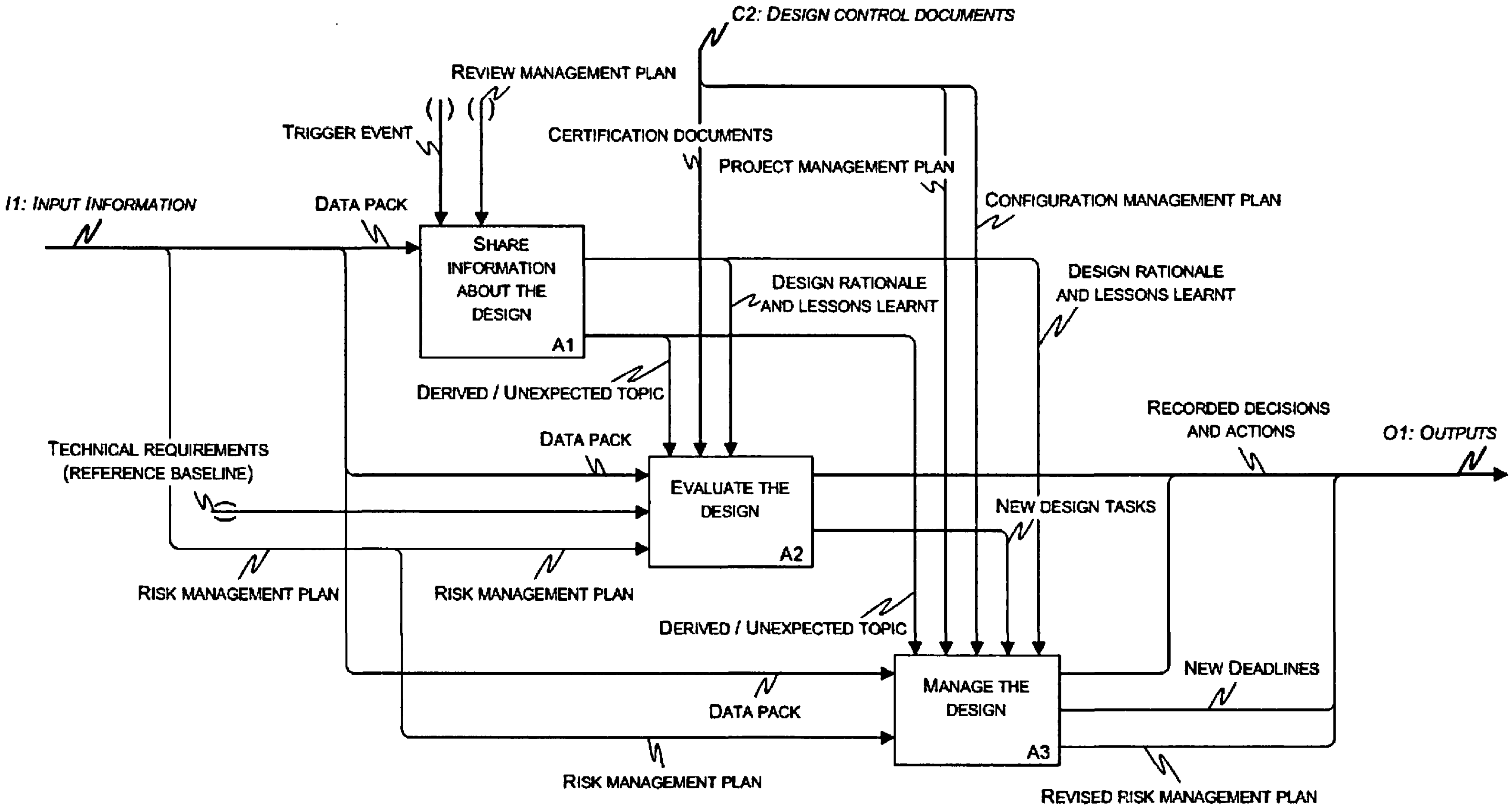


Figure 3.6 The IDEF$_0$ detail diagram of an aerospace design review process

It is not the intent of this thesis to fully describe the $IDEF_0$ detail diagram; instead, table 3.5 lists and describes key elements of the model to help the reader gain a general understanding of the model proposed.

***Table 3.5** Description of key elements of the $IDEF_0$ detail diagram*

Name of the element	Role(s) in the $IDEF_0$ diagram	Description
Data pack	Input for A1, A2, A3	Usually contains information from the suppliers, reports from the engineering teams involved, and a discrepancies register where participants have noted issues and problems in advance of the meeting. It will also include information specific to the type of review.
Risk management plan	Input for A2, A3	Used to evaluate the design achievements (A2) and manage the design process (A3) based on a risk assessment of the design tasks under review. The plan is updated according to the decisions made during the design review.
Trigger event	Control for A1	Acts upon the information sharing process (A1) as discussions dictated by external events or requested internally, but not initially planned in the meeting agenda, can force their way into the design review.
Review management plan	Control for A1	Includes the objectives of the review, the list of applicable documents (most of which are provided in the data pack), roles and responsibilities, an agenda, and a summary of the review process. This information should be acknowledged by all participants before the meeting takes place and is mainly used during the event to share information about the design achievements (A1) in an orderly way.
Certification documents	Control for A2	Part of the design control documents (C2). They ensure compliance with quality and certification regulations during the design evaluation activities. Certification documents evolve with the development of the project. The "Quality Assurance Plan" is used for the RR, the "Certification Basis" is ready for the final CR, the "Type Certification Compliance System" guides the PDR, and the "Means of Compliance" needs to be issued before the CDR.
Design rationale and lessons learnt	Output of A1 Control for A2, A3	These elements have been described in §2.3. They are sometimes made explicit and available for reuse when attached to the record of decisions, actions, and deadlines.

It is important to note that the "outputs" (O1) of the design review are not only the documents compiled in the review report (list of actions, minutes, deadlines etc.) but also include personal notes, and more generally the individual experience and knowledge retained by each participant.

Finally, the information sharing activity (A1) generates "rationale and lessons learnt" which influence both the evaluation and design management activities (A2 and A3).

Although some of the rationale and lessons learnt discussed during the meeting are recorded explicitly, most of this information, as shown in figure 3.5, is part of an internal process and therefore only retained in the participants' memories.

The following section will review in detail two critical elements used in both the process- and the object-oriented models described previously: the participants and artefacts. Participants are main sources of knowledge and information during meetings, while artefacts are present in a great number of the meeting elements used in the models.

3. THE ROLE OF PARTICIPANTS AND ARTEFACTS

The two models of a design meeting detailed in section 2 provide an in depth understanding of its typical constitutive elements and generic information processes. Based on this work, it is now possible to outline a broad definition of a design meeting:

A design meeting is a set of communication processes which take place in a synchronous or asynchronous manner over issues linked to spontaneous or predetermined topics. A design meeting aims at achieving general agreement over design issues by spreading information between at least 2 participants with the support of specific artefacts.

This dictionary style definition relates the essential dimensions of a design meeting in which the role of "participants" and "artefacts" have a special place. This section will therefore review how participants are expected to interact and make use of artefacts during design meetings.

3.1. The role of participants in design meetings

Following the definitions given for the object-oriented model, participants of a design meeting take on 3 roles (meeting role, project role, and company role). The role of a participant in a project is typically linked to expertise and experience, while her/his role in the company can be seen as a reference title used across projects. Meeting roles will typically vary according to the formality of the meeting. In the case of an aerospace design review four roles can be outlined: the chairperson, the secretary, the reviewer(s) and the member(s) of the project team. Table 3.6 summarises the expected responsibilities of each design review participant according to their role.

***Table 3.6** Expected responsibilities of design review participants according to their role*

Design review role	Responsibilities
Chairperson	Nominate secretary and review team in consultation with the project leader and the chief engineer. Chair the meeting and facilitate dialog between the review team and the project team.
Secretary	Prepare agenda, record the formal communication during the review and issue the minutes. Distribution of all input and output documents to the participants.
Reviewer	Ensure completeness of review. Establish corrective recommendations and way(s) to proceed.
Project team member	Create, organise and present the design data to the review team. Carry out the actions outlined by the review team.

The "facilitator" is another role sometimes reported in certain domains of activity, business and management are good examples. The duties involve negotiation and decision facilitation in meetings where conflicts and disputes can arise. Although in design reviews the facilitation role is easily taken on by the chairperson because participants work together to achieve consensus, meeting facilitation technologies provide nonetheless interesting insights into possible information capture approaches. These technologies along with others used in the context of a meeting will be reviewed in section 4.

Overall, from a design review process perspective, participants can be grouped in three distinctive parties: the chairperson and secretary orchestrate the meeting, the reviewers evaluate the design achievements, and the project team members present and justify the proposed design. It is important to note that the review team and project team are not in opposition to one another but are working together to improve the design. The review team must help the project team while the project team must take account of the remarks made by the review team in a positive manner. A design review can even be broken up into work groups focussed on specific aspects of the design.

The study of participant roles during meetings has led to interrogations such as the optimum size of a review team or the influence of a participant's place in the company hierarchy (D'Astous *et al.* 2001). Results from software design studies conclusively show that during peer review meetings, participants spend most of their time interacting on the content of the designed product while the design process is an expeditious activity (D'Astous *et al.* 2004). In a mechanical engineering context, however, discussions related to the design process are expected have a far more important role to play; aerospace engineering teams involve stakeholders from different companies who need to share, evaluate, and manage information about their activities according to their respective organizational processes.

As illustrated in figure 3.6, participants are the main mechanisms which influence the meeting activities of a design review. What is not shown in the $IDEF_0$ detail diagram, however, is their capacity to generate and retain the important information from these collaborative events. The participants are the knowledge and information creating sources, and are responsible for the explicit rationale and lessons learnt shared during a review. These knowledge elements are usually kept in their memories and personal notes (McAlpine *et al.* 2006), but seldom in the official records of the meeting. A complete investigation into the content and structure of current design review records will be detailed later on, in chapter 6 of this thesis.

3.2. The use of artefacts during engineering meetings

Engineering meetings and especially design reviews involve multiple stakeholders who see the object of design from different perspectives and ultimately use different "dialects" to describe it (Bucciarelli 2002). The participants of a design review effectively work in different *"object worlds"* (Bucciarelli 1994), and they rely on artefacts to enable information sharing, negotiating, or making decisions about the design and its process. Artefacts can be loosely defined as *"objects created by a human being"* (New Oxford American Dictionary 2005). In the context of a product development process, they act as interface communication elements or *"boundary objects"* and are used to *"bridge thought and object, function and structure"* (Bucciarelli 2002).

Perry and Sanderson (1998) have reported two case studies in which they analyse the range and roles of artefacts used by designers. Table 3.7 is an adaptation of their design artefact categorisation; 8 categories group the variety of artefacts encountered according to their role in design activities. The table proposes examples in the specific case of design meeting activities. Each category is characterised by a "categorisation type". Indeed, "inclusive" categories are composed of elements which might contain "specialised" artefact categories, e.g. presentation slides (primarily a communication artefact) might include slides which could individually be considered as drawing, calculation, or testing artefacts. It is also important to note that although most of the artefacts cited in the table can be used in a variety of design situations, some of them are specific to meetings (agendas, minutes, presentation slides).

Table 3.7 Categorisation of artefacts in engineering design with examples for meeting situations

Artefact types	Categorisation type	Examples for design meeting activities
Office	Inclusive	Pencil, paper, calculator, ruler, office software
Drawing	Specialised	Sketches, 2D layouts, diagrams, pictures, CAD pictures and animations
Activity management	Inclusive	Standards, guidelines, agenda, schedules (Gantt charts), project / process map, control and management documents
Information management	Inclusive	Personal folders, project logbooks, laptop, Tablet PC, PDA, Bill of Materials
Calculation	Specialised	Graphs, charts, spreadsheets
Communication	Inclusive	Telephone, videoconferencing equipment, whiteboard, presentation slides, reports, meeting minutes, actions list
Component	Specialised	Existing part, 3D physical prototype, 3D Digital Mock-Up
Testing	Specialised	Test rig (e.g. on video), 3D dynamic analysis

Source: Perry and Sanderson (1998)

Perry and Sanderson (1998) make a further distinction between *"design"* and *"procedural"* artefacts:

> *"Design artefacts represent thought about a design, whereas procedural artefacts convey the anticipated design process and help to orient people to it."*

Although this important distinction recalls the notions introduced in chapter 2 relating to product and process knowledge, it does not account for the artefacts that can play a role in both situations (graphs, diagrams, reports etc.). The categorisation presented in table 3.7 is more precise and gives an accurate account of the different roles played by artefacts during the product development process.

It is also possible to relate the various artefacts mentioned in the IDEF$_0$ models presented in §2.2 to the different categories listed in table 3.7. As a general rule:

- Artefacts placed as controls relative to the activity boxes can be classified as activity management artefacts.
- Artefacts placed as outputs relative to the activity boxes can be classified as activity management or communication artefacts
- Artefacts placed as mechanisms relative to the activity boxes can be classified as communication, information management, or office artefacts.

- Artefacts belonging to the information inputs are more wide ranging and can be classified as drawing, activity management, information management, communication, calculation, component, or testing artefacts.

Finally, chapter 6 of this thesis will look in detail at a specific meeting artefact: the minutes of the meeting. In the case of design reviews, minutes are often included in a review report which compiles different artefacts such as a list of actions, a list of decisions, a descriptive account of the event, etc. Although this document must be considered as a historical record of the event with a number of legal implications in the case of formal meetings, e.g. ISO 9000 quality standard (2005), its content and structure are only loosely addressed in publications in the field of meeting management (e.g. Gutman 1998, Markel 1994, Spencer and Pruss 1997). The recommendations made by these authors are often based on personal experience and, just as a number of meeting management techniques outlined in the next section, they only too rarely provide an explicit rationale for the guidelines proposed.

4. MEETING MANAGEMENT AND RELATED TECHNOLOGIES

A meeting can take place in both collocated and distributed situations. Indeed, modern technologies such as e-mail, chat, e-rooms, video conferencing, digital libraries (Juster *et al.* 2004), and other Computer Supported Cooperative Work (CSCW) packages form the new communication toolkit for an engineer taking part in a "virtual project" (Evaristo and Scudder 2000) or member of a "virtual team" (Baird *et al.* 2000). The actual reasons behind temporally and physically distributed work arrangements are multiple (Hinds and Kiesler 2002): company mergers and acquisitions, the need for specific expertise, establishing presence around the globe, etc. In engineering, distributed work has a lot to do with specific attributes of the "globalization" phenomenon, namely the successful management of costs and risks (Baird *et al.* 2000). At present, new technologies have essentially focussed on reducing the geographic distances and the time differences (Peña-Mora and Hussein 1998). More needs to be done in terms of organisational distances and cultural differences for the productivity gap between collocated and distributed work to be bridged.

It is undeniable that distributed work situations require mediated communication, but research shows that complex global organizations and social networks cannot function properly without face-to-face communication (Nardi and Whittaker 2002). Collocated work is, without a doubt, the most effective way to share information within teams (Olson *et al.* 2002), but also presents certain negative aspects such as interruptions, emotional expense, and low productivity in meetings (Nardi and Whittaker 2002). For distributed design teams, the main barriers to optimal team performance are the use of common mental design representations and references (Eckert *et al.* 2005), reaching a common understanding of the problem, the design requirements, the objectives, the design process, and the roles of the participants (Larsson 2003; Toye *et al.* 1993). These aspects of a project are typically discussed and addressed over synchronous meetings of different types and levels of formality.

This section reviews the most significant progress made by tools and technologies for the benefit of meetings in collocated or distributed situations. Current developments have been grouped in two categories: "meeting facilitation" and "information capture tools for meetings". While meeting facilitation can be directed towards both the content and structure elements of a meeting, information capture tools and techniques, on the other hand, are exclusively designed for the efficient extraction of meeting content.

4.1. Meeting facilitation

As mentioned previously, facilitating meetings can be understood as helping the organization and execution of the event, or as supporting efficient communication during meeting activities. Meeting facilitation tools and techniques can therefore be categorised as "resources" or "communication support" in both meeting models presented in section 2. In terms of technologies, there are also two fields of expertise in which meeting facilitation has been a focus for research: Computer Supported Cooperative Work (CSCW) and Group Decision Support Systems (GDSS). These two areas of IT research belong to a wider family of computer tools commonly referred to as "Groupware", defined by Ellis (1991) as:

> *"Computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment."*

4.1.1. Facilitating temporal and physical distribution

One of the widely used CSCW developments for distributed meetings is videoconferencing technology. Nowadays, these technologies use either a group setting, where the equipment is placed in a dedicated conferencing room, or a personal setting in which videoconferencing software is installed on the participant's computer (Wilcox 2000).

The technologies used in the group videoconferencing room simply aim at sharing information and artefacts through audio and video communication channels. This enables remote participants and groups of participants to hold a virtual and synchronous meeting. Videoconferencing is by no means a new concept; it was first developed in the early 1950s by AT&T (American Telephone and Telegraph corporation), but gained real interest in the 1970s.

Web conferencing, or desktop videoconferencing (Isaacs and Tang 1994), is another type of videoconferencing approach, where each participant must use a computer in order to communicate with the others. These CSCW environments use dedicated software and the Internet, and are much cheaper to run than standard videoconferencing technologies. Also, they support both synchronous and asynchronous meeting situations. Web conferencing can be seen as an advanced Instant Messaging (IM) system where the use of a webcam and a microphone expands IM to a real videoconference experience. These settings permit information sharing equivalent to standard videoconferencing suites, but the quality of audio and video transmissions is diminished. This, however, is only a minor setback as video and audio broadcasting capabilities through the Internet are continuously improving. Desktop videoconferencing is undoubtedly the distributed meeting facilitation approach of the future, but efforts must be made by companies in order to provide adequate office settings, employee training, and more importantly information security. Although Web conferencing systems have a lot to offer, the author has not witnessed their use in the aerospace industry; possible reasons for this are the "open office" settings used in engineering departments and information security concerns. Most of the research that aims at introducing desktop videoconferencing in product development teams acknowledges that these tools are designed to support informal meetings with a small number of participants (Braun *et al.* 2002, Yankelovich *et al.* 2004).

Finally, web conferencing systems have started to pave the way towards virtual meeting rooms, where a complete virtual environment is set up to enable large scale meetings with integrated tools to manage the event and efficiently share information (Powell 2004).

Overall, the videoconferencing technologies presented previously have helped to develop a new set of "virtually collocated" meetings. They have a successful record in educational settings (Shi *et al.* 2003), but they cannot replace face-to-face collaboration for certain critical situations in the workplace: controversial topics, debates, meetings with participants who have never met each other, etc. (Egido 1988, Isaacs and Tang 1994). In face-to-face meetings, even nowadays, technology requirements are usually reduced to a minimum: a meeting room will use a computer (laptop or desktop) connected to a projector in order to share information.

4.1.2. Facilitating the planning and organisation of a meeting

Organisation and planning are essential requirements towards successful meetings (Garcia *et al.* 2003). For formal meetings, such as design reviews, the preparation is guided by a set of guidelines or even standards, which dictate the necessary planning activities, as previously mentioned in chapter 1. Still, these procedures remain very basic and without associated templates, forms, or practical guidelines, the preparation of a meeting will vary significantly according to the secretary and chair person.

To illustrate current trends aimed at the improvement of meeting planning, two examples have been chosen and detailed in the following paragraphs.

Garcia *et al.* (2003) have focussed their research on the role, use, and impact of predefined agendas in the case of meetings for a building construction project. The study showed that over 30% of the predetermined topics only concerned a small proportion of the participants and therefore did not justify their inclusion in the initial meeting agenda. In order to counter the agenda planning problem, the research team proposed a game theory approach (the Vickrey-Clarke-Groves method), whereby participants could vote on the proposed agenda in advance of the meeting. The voting system was available online through the Survey Monkey tool (SurveyMonkey 1999). The new "voted" agendas reported by Garcia *et al.* (2003) included all the original topics, but each item was labelled according to 3 possible criteria: "remove from meeting", "discuss during meeting", or "discuss during a small group meeting". The findings demonstrate that a careful agenda planning, which might seem like an innocuous activity at a first glance, can indeed play an important role to achieve an effective, efficient, and value-added meeting (Garcia *et al.* 2003).

The organisation of a formal meeting involves a number of preparatory tasks. New commercial software has been developed to address these issues. To illustrate its capabilities and limitations, the 4D Meetings software was chosen as an example. 4D meetings is available free of charge and can be implemented on different computer Operating Systems (4D Meetings 2005). It essentially proposes a set of tools to manage the list of participants, the input and output documentation, and the synchronisation of emails. It does offer the user standard templates for agendas and minutes, and comes with a meeting database where all the files and documents generated from a meeting can be organised and archived. These tools provide a practical structure of meeting documentation but do not add any value (in terms of information and knowledge) to the content of these documents.

4.1.3. Facilitating meeting activities

A number of publications are available on the effective management of meeting activities, e.g. Streibel (2003), Tropman (2003), Weynton (2002), but these recommendations are often based on personal experiences and beliefs. Although the ideas proposed are interesting and valid to a certain point, they are usually formulated in a specific context – business meetings – and one could even guess that the experience reported in these publications refers to specific work environments.

Nevertheless, some well known meeting management techniques, such as brainstorming (Osborn 1963), provide an effective answer to particular meeting goals, in this case the generation of new concepts for problem solving. These techniques, however, must be used in certain circumstances and will very rarely guide a complete meeting from start to finish. They also require at least one of the participants to fully master the technique and therefore the use of a meeting facilitator, as suggested in §3.1, is often crucial.

A meeting facilitator is usually a person, preferably with no ties or involvement in the subjects of discussion. GDSS, also known as Group Support Systems (GSS), are a set of tools that can be used by the facilitator or by each one of the participants to improve the effectiveness of the decision process (Pervan and Atkinson 1995). GDSS research and development has focused on three main bodies of knowledge: human behaviour, decision-making models, and Information Technologies. Facilitation tasks and tools often have an impact on the meeting process and its content (de Veerde *et al.* 2002). GDSS systems, such as Electronic Brainstorming, are usually versatile in the sense that they can support both distributed and collocated team settings. The benefits of Electronic Brainstorming, for example, over its standard face-to-face brainstorming counterpart have been measured and verified in a number of experiments (Kerr and Murthy 2004): participants generate more ideas, including relevant ideas.

In general, facilitation tools and techniques offer well established benefits for team meetings, but only for certain critical activities and in well determined contexts. GDSS research does converge on the fact that optimum productivity and efficiency during meetings can be reached through a balanced blend of computer-mediated and face-to-face communications. Face-to-face settings should be especially encouraged to reduce equivocality, for negotiation and bargaining situations, and more generally when the participants are motivated to maximise joint outcomes (Sheffield 1995).

4.2. Information capture tools for meetings

The previous section has outlined facilitation tools and strategies to effectively manage the meeting event in a variety of settings. On the next page, table 3.8 summarises a number of technologies that can be used to capture the information generated by meeting activities.

In table 3.8, the technologies have been classified according to the format of the resulting content extraction. Each technology has also been labelled according to the type of technology under consideration (Hardware or Software) and whether the tool has been designed for an individual use or for group/team purposes.

Overall, the table clearly highlights the dominance of text-based approaches for the final capture of meetings contents. Various members of the Design Information and Knowledge (DIAK) research group at the University of Bath, including the author, have tested the digital logbook (Tablet PC) and the digital pen. Handwriting recognition is a mature technology and offers interesting prospects for the integration of annotations, sketches and personal notes in engineering information systems (McAlpine *et al.* 2006). From a meeting perspective, the Tablet PC and the digital pen could become important information capture hardware, each one with distinctive roles according to their strengths. Indeed, the Tablet PC is a highly versatile and compact computer that incorporates both a digital handwriting input device (slate) and most office software. The handwriting experience, however, is not as smooth as the digital pen, where the user keeps the familiarity of pen and paper. These seemingly innocuous observations are nonetheless important and could strongly influence future meeting scenarios including both technologies. The Tablet PC, because of its versatility and the fact that it does not hide the user from the rest of the group (unlike a laptop), could become an ideal companion for the meeting secretary. The digital pen, on the other hand, is a simple and efficient tool to capture personal notes and could therefore be used by the rest of the participants during the event. The intelligent integration of a Tablet PC and digital pens in a meeting environment clearly offers the opportunity to capture the full extent of the informal written information generated.

Table 3.8 *Classification of information capture tool for meetings*

Information format	Capture technology	H/S (1)	I/G (2)	Comments and references
Textual and Pictorial	Logbook	H	I	Paper based or digital (Tablet PC, digital pens) with handwriting recognition capabilities. Standard tool to take personal notes (McAlpine *et al.* 2006).
	Computer	H	I	Computers, especially laptops, enable the sharing of information between participants using a projector. Not recommended to take personal notes during meeting.
	Digital pen	H	I	Used on a paper surface augmented by a digital pattern grid. Captures and tracks the strokes made by the user. Alternative to the Tablet PC. The digital strokes are then downloaded to a computer to obtain the electronic version of the notes (Guimbretière 2003).
	Digital whiteboard	S	G	Used in videoconferencing and collocated situations. Provides a large shared space, but the annotations captured are hard to reuse (Elrod *et al.* 1992; He *et al.* 2003; Shi *et al.* 2003).
	4D meetings	S	I	As discussed in §4.1.2, this type of software proposes a very basic capture template.
	Dialog Mapping	S	G	Enables the user to map out the questions and the answers that arise during spoken discourse. The dialog is mapped using an IBIS approach (see Ch.2, §4.3.1).
	Quindi meeting companion	S	I	New software that enables to capture, annotate and time-stamp meeting activities using textual, video, and audio cues (Rosenschein 2004). Requires a laptop.
Gesture	Video recording equipment	H	G	Meetings can be recorded on video. Issues: duration, confidentiality, information structure.
	Quindi meeting companion	S	I	Web-cam records the meeting and the audio/video file is indexed according to notes taken, artefacts used (presentation slides), and other predetermined markers.
Verbal	Audio recording equipment	H	G	Meetings can be recorded on audiotapes. Issues: duration, confidentiality, speaker recognition, information structure.
	Microsoft OneNote	S	I	The standard logbook software provided with the Tablet PC (OneNote 2003). Audio snippets can be integrated and time-stamped to the note taking activity. Computer-based version of the audio notebook (Stifelman *et al.* 2001).
	Speech Recognition	S	G	Multi-speaker recognition is still under development. Advances in speech recognition would let envisage automated meeting capture tools. Issues: vocabulary requirements, software training, multi-speaker recognition (Brown *et al.* 2001).
	Quindi meeting companion	S	I	If no web-cam is linked to the software, the computer records the audio and this file can be indexed instead.

Notes for table 3.8:

[1] *Refers to Hardware (H) or Software (S) technology*

[2] *Refers to whether the input is managed by an Individual (I) or by a Group (G)*

When it comes to the management of the information captured during meetings, regardless of the format, two distinct approaches can be outlined from the technologies summarised in table 3.8: the automated approach and the human-facilitated approach. The automated approach is highly dependent on the success of speech and semantic recognition technologies. This field of research belongs to the domain of Artificial Intelligence and more specifically of natural language processing. IBM and ICSI are aiming to integrate speech recognition in innovative meeting facilitation software, such as the Meeting Miner (Brown *et al.* 2001). These hi-tech projects, however, stumble upon major technological barriers, namely: multi-speaker recognition, specialised lexicons, and natural language processing performance especially in the context of meetings (Wooters *et al.* 2005). These issues are often related to a number of properties of spontaneous speech (hidden punctuation, disfluencies, turn-taking, emotions) which are still not properly integrated in current research approaches (Shriberg 2005).

In table 3.8, the Quindi Meeting Companion is the only tool that uses the three information formats to record meetings. This new software enables the user to index the video (or audio) recording of the meeting using a variety of markers: snapshots, presentation slides, textual comments, etc. (Rosenschein 2004). Quindi Meeting Companion is to date the most advanced commercially available meeting capture software and therefore the best example of a human-facilitated solution. Of course, the software is computer-mediated but still requires the input of a human user to achieve its goals: indexing video records of meetings. It was trialed by the author on a variety of case studies (detailed in chapter 4). Although this solution presents a number of advantages clearly promoted by the software company, it did not spark much interest when demonstrated at Airbus UK. Several reasons can be put forward:

- *The "Big Brother" syndrome:* video and audio recorders are not welcome in the workplace; they induce suspicions amongst workers of unethical performance measurements.
- *Confidentiality and information sharing issues:* aerospace design reviews very often include participants from different companies, which are direct competitors across the various projects developed in the aerospace industry. Classic textual accounts of meetings have the advantage of being more impersonal and easily customisable according to the involved parties.

- *Deficiencies linked to the design of the software:* Quindi Meeting Companion is a new tool, and several improvements could be made. The author noted: the lack of archiving structure for the "quindi meeting" records; the limited, if not inexistent, customisation possibilities; the poor level of structure of the "quindi meeting" minutes sheet; absence of structured "export" features to other office software; more can be done to expand the types of markers used to index the video record.

Once a structured record of the meeting is established, it is possible to envisage a post-processing activity whereby the meaning and essential knowledge can be extracted. The next chapter will detail research tools and techniques developed to analyse and understand aerospace design reviews; even if developed for a research purpose, these analytical tools offer promising insights into meeting information and knowledge capture practices.

CHAPTER SUMMARY

The single most important practical aspect for an efficient study of spoken discourse is the use of verbatim transcripts. These enable the precise analysis of verbal transactions between participants based on a predetermined coding scheme. The Transcript Coding Scheme (TCS) developed for the purpose of the DTM case studies will be the subject of the next chapter, but its coding criteria are the result of a comparative study of the terms used in the engineering domain for meeting analysis presented in this chapter.

The comparative study has first exposed the lack of cohesion amongst the pool of concepts used by research teams to describe and analyse meetings. The comparison of the concepts encountered in the literature therefore aimed at building a unified view on the topic of meeting analysis; in practice, this was achieved using matrices. The resulting terminology selected by the author enabled to build two complementary models of design meetings: an object-oriented model and a process-oriented model. These models provide the necessary context and structure for the development of a number of different meeting analysis tools, including the TCS, which will be described in chapter 4.

The object-oriented model is a simple hierarchical classification of meeting elements, essential to observe and analyse meetings in an engineering context. Each entity in the model is defined by its attributes and possible values. The hierarchy is divided into two main branches: one branch groups the entities related to the structure of the meeting (elements on which the meeting needs to be built, e.g. participants, resources, etc.), while the other branch is composed of entities related to the content of the meeting (elements which help characterise the nature and content of the information transactions that take place, e.g. topic of conversation, input information, communication elements, etc.).

The process-oriented model uses an $IDEF_0$ approach to represent the various information processes which are expected to occur during a design review. This model shows how the activity of "reviewing the design achievements", core to design review meetings, can be decomposed in a sub-set of 3 interrelated activities, namely: "share information about the design", "evaluate the design", and "manage the design". The detailed $IDEF_0$ model of a design review proposed in this chapter is illustrated with information elements and artefacts typically encountered in aircraft development projects. Ultimately, this model shows how key knowledge elements, i.e. design rationale and lessons learnt, are transferred between the 3 main design review activities but are never truly related to any of the outputs of the design review process.

From the two meeting models described above, "participants" and "artefacts" have been singled out by the author for further investigation. Indeed, participants are the knowledge and information creating sources in a meeting, and are responsible for the explicit rationale and lessons learnt shared during a review. Overall, from a design review process perspective, the role of participants can be grouped in three distinctive parties: the chairperson and secretary orchestrate the meeting, the reviewers evaluate the design achievements, and the project team members present and justify the proposed design. The notion of "artefact" plays a role in a number of elements used in the two meeting models. The participants rely on artefacts to enable information sharing, negotiating, or making decisions about the design and its process. In the context of a product development process, they act as interface communication elements and are used to *"bridge thought and object, function and structure"* (Bucciarelli 2002). In a design review, artefacts play a role in all the elements (mechanisms, controls, inputs, and outputs) of its information process model; a categorisation of the different types of artefacts according to their role in design activities has therefore been proposed based on the work reported by Perry and Sanderson (1998). Within this classification, a specific artefact – the meeting minutes – will be the focus of chapter 6.

The study of engineering design meetings has led to an understanding of the main theoretical mechanisms reported in the literature. In the context of the DTM research, where improved methods and tools for meeting capture are sought, current technologies used during meetings is also an essential topic that needs to be reviewed. In the concluding section of this chapter, technologies have therefore been examined according to two categories: "meeting facilitation" tools and "information capture" tools. This review will ultimately serve to define the optimal technological solutions that could be integrated to the meeting capture strategy proposed in chapter 6.

CHAPTER 4

NEW APPROACHES TO ANALYSE DESIGN MEETINGS

As discussed in the previous chapters, understanding the mechanisms of a meeting and its working environment is critical to building an effective knowledge-oriented recording strategy. To this effect, chapter 4 focuses on a set of tools and techniques developed to characterise and analyse in depth the transactions observed during a number of case studies. The first methodology developed – the Transcript Coding Scheme (TCS) – uses an intelligent segmentation of meeting discourse transcriptions. The coding criteria used in the TCS are directly derived from the literature reviewed in chapter 3. To bypass the time consuming transcribing operation, a different approach was also adopted whereby a meeting observer uses a specially designed Meeting Capture Template (MCT) to record the important information elements as the meeting takes place. The interpretation of the results in terms of decisions, actions, rationale and lessons learnt is based on a third methodology – an Information Mapping Technique (IMT). In the next chapter, the results generated through the application of these 3 new meeting analysis tools to the various DTM case studies will serve to characterise design reviews in terms of communication, information, and knowledge processes.

1. MONITORING DESIGN MEETINGS: THE DTM CASE STUDIES

As discussed in chapter 1, the research reported in this thesis grounds its findings in empirical data taken from the monitoring of engineering teams working in design review situations. Since 2003, the DTM project has gathered data and experience from 3 distinct case studies: the observation of an undergraduate student design project at the University of Bath (UK), the recording of aerospace design reviews held at Airbus UK, and the complete monitoring of a large scale aerospace design project at the École Polytechnique de Montréal (Canada).

Table 4.1 outlines briefly the number of meetings observed, the number of participants involved, the average duration of a meeting, and the research objectives for each one of the 3 case studies. The following paragraphs will provide more detail on the context in which these 3 case studies took place, and how they were used to develop the set of analytical tools presented in the later sections of this chapter, i.e. the Transcript Coding Scheme (TCS), the Meeting Capture Templates (MCT), and the Information Mapping Technique (IMT).

***Table 4.1** Summary of the 3 DTM case studies*

Case study	No. of Meetings	No. of participants	Duration	Research objectives
Observation of a student design team	10	5-7	20-45min	• Test recording equipment and strategy • Acquire awareness of monitoring issues
Airbus UK design reviews	2	9-13	2½-3½ hrs	• Acquire industrial data for detailed analysis • Observe industrial practices
CAMAQ project	4	20-25	2-3 hrs	• Acquire data over the duration of the design phases of a project • Test research findings, tools, and methods

1.1. Case study 1: observation of a student design team at the University of Bath

In 2003, a first case study was initialised: the observation of a student design team at the University of Bath. These design projects are a compulsory course for mechanical engineering students during their third year of studies. The team chosen was composed of 4 students who had the task of redesigning a portable Brinell hardness tester for a small company. Two academic supervisors supported the students. Ten meetings were monitored in total, 8 were recorded on audio tapes and 2 were simply observed by the author.

This first case study was mainly an opportunity to organise a simple recording methodology for meetings and outline the foreseeable technical, organisational and human issues linked to the monitoring of design meetings.

From these first initial recordings, several practical remarks were put forward:

- The recording environment is very important: the students were given a workspace in a noisy environment and a few recordings were not of a sufficient quality to be further exploited.
- The workspace was also used as the main meeting room; the artefacts used were therefore part of the workspace. In terms of facilities, the students disposed of a traditional blackboard used for calculations and sketches, and panels on which they could display relevant documentation and findings.
- For this particular project, the students were asked to write-up minutes for each one of these meetings. This task was addressed loosely by the students and the content of the minutes, generally very poor, varied significantly according to the secretary.

Because of the level of experience of the participants and the relative informality of the meeting setting, the recordings with the best audio quality were transcribed in order to gain some experience, but these transcripts were not analysed in any depth as the events were not representative of formal design reviews. Overall, this case study was an ideal opportunity to test various recording installations in order to select the best compromise between audio quality and meeting disruption.

At first, a professional Mini Disc (MD) recorder linked to high quality microphones was used; this equipment was bulky and too visible. This intimidated the students and prevented them from having a normal conversation. The microphones were therefore reduced to a small table microphone about the size of half a deck of cards. For one of the meetings, the recording was made directly through a Tablet PC's soundcard, but the results were not as good as expected, and ultimately up to 15% of the conversations could not be transcribed. It was therefore decided to reverse to the portable MD setting. The audio stream was then converted to a WAV format by linking the MD to a computer. On the computer, the audio stream could then be improved by cutting out background noise and using a digital equalizer.

1.2. Case study 2: design reviews at Airbus UK

Two "real" design reviews were monitored on site at Airbus UK: a Requirement Review (RR) and a Preliminary Design Review (PDR). Although the two meetings involved engineers from the same department, these were related to different aircraft programs. The RR was held internally and prepared the redesign of a fuel leak detector system involving one of the fuel equipment suppliers for the A321 aircraft. The PDR reviewed the propositions made by another supplier for the redesign of a faulty part in the assembly of a trim tank pump on the A340 aircraft. In both cases, the "intervene" element had to be omitted from the research cycle (see chapter 1, §2.2) to avoid disturbing the engineers. The data collection taken from these two reviews provided a unique insight into the industrial realities of the aerospace design control process.

The PDR covered the redesign proposal made by the supplier in order to modify the thrust washer pin that initially caused a trim tank pump failure. The thrust washer pins are part of the rotor assembly shaft as shown in figure 4.1.

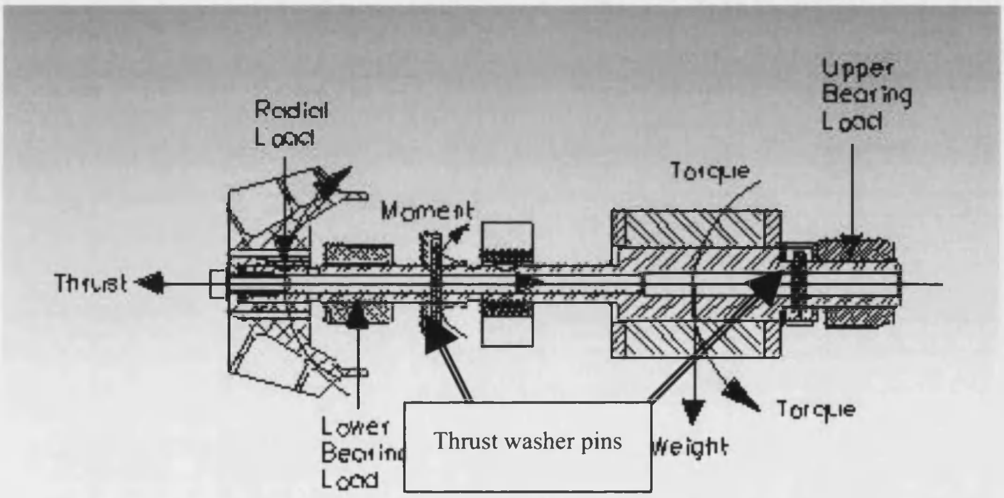


Figure 4.1 *Position of the thrust washer pins in the trim tank pump rotor assembly*

During this design review meeting, the following items were reviewed:

- Thrust washer pin design change proposal
- Stator corrosion and proposed process improvements

The review panel for the Airbus UK team working on the project was composed of 8 engineers specialised in various fields of mechanical engineering but all part of the fuel systems team. The supplier was represented by a single chief engineer who had to present the solution proposed for the redesign of the failed parts in the trim tank pump. The meeting lasted over 3 hours. The artefacts used during this meeting were:

- Two PowerPoint presentations made by the supplier
- Parts of the trim tank pump related to the failure for display
- Formal input documents emailed between participants before the event
- The agenda set in advance as required by the design review policy at Airbus

The RR was an internal design review, with the aim to ensure that all the requirements for the A321 fuel leak detection system development were identified, captured, and valid. The proposed modifications include a new fuel leak detection function and provision for dry bay deletion (where dry bays are not required). The overall goal of the project was to homogenize the "single aisle" (single aisle is the informal Airbus name for the A320 aircraft and its derivatives) fleet for fuel leak detection and dry bay deletion functions. All of the input documents were distributed to the stakeholders ahead of the review and the comments and feedback from the supplier, although not present, were informally integrated to the meeting.

The meeting activities observed during the RR essentially consisted in the review of a number of engineering and project management documents:

- The certification plan
- The equipment specification
- The management plan
- The milestone plan

In addition to these formal documents, the agenda and the Statement of Work were also part of the artefacts used during the RR.

The two Airbus UK design reviews were transcribed completely by the author; the transcribing process followed the steps outlined in figure 4.2. Although a number of companies offer transcribing services, the level of specialisation of the vocabulary employed and the number of abbreviations used in the discourse did not encourage the pursuit of this service.

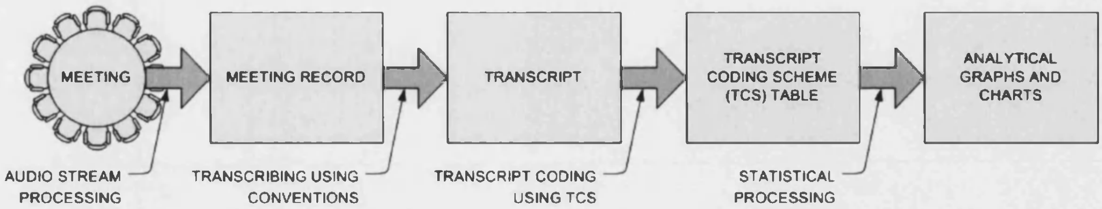


Figure 4.2 *The transcribing process steps*

Figure 4.2 illustrates the manual process adopted to achieve the results which will be presented in the next chapter. Transcribing was, by far, the most time consuming activity in the process. Furthermore, the time necessary to transcribe audio varied a lot according to the quality of the recording. In the PDR meeting for example, the worst case in terms of audio quality, 1 minute of recorded speech could take up to 20 minutes to transcribe correctly. For the RR, the meeting environment was better suited for audio recording, and 1 minute of recorded speech took approximately 10 minutes to transcribe. The Transcript Coding Scheme will be detailed in section 2.

The overall transcribing procedure shown in figure 4.2 was always considered by the author as a research approach to understand meetings and was therefore never designed with the intent of building an application to automatically capture meeting contents.

1.3. Case study 3: the CAMAQ project at the École Polytechnique de Montréal

Fifteen students participating in the "CAMAQ project", a large scale aerospace design effort, were monitored during the whole length of the project in 2004/2005. This hands-on project was developed with the Centre for Aerospace Manpower Activities in Quebec (CAMAQ), IBM, and three large aerospace companies based in the region of Montreal: Bell Helicopter Textron Canada, Bombardier Aerospace, and Pratt & Whitney Canada. This unique programme, which covers two academic semesters, is offered at the École Polytechnique to students enrolled in an aerospace engineering Master's degree in one of the universities in the province of Quebec. The project involves the redesign of an aircraft engine pylon to enable the retrofit of a new engine and is controlled by a design review process, based on industrial practices, in which a team of industrial experts review the design achievements presented by the graduate student team. To accomplish their task, the students use a dedicated workspace, the "CAMAQ laboratory", which offers access to state of the art Digital Mock-Up (DMU) and Product Lifecycle Management (PLM) technologies.

The CAMAQ project answers at least two major preoccupations outlined by employers in the aerospace industry: it exposes the students to current industrial practices that are not usually experienced by engineers before several years of work in the trade, and it demonstrates the impact of new technologies used by aerospace product development teams. This novel educational experience has become part of the Mechanical Engineering curriculum strategy at École Polytechnique – the Virtual Environment option – directed towards familiarizing students to virtual product development technologies and methodologies (Fortin *et al.* 2006).

At the beginning of the first semester, the industrial experts representing each sponsor company dispatch all the necessary information required to complete the project: standards, company guidelines, design manuals, aircraft and engine geometries, CAD models, 2D layouts, certification regulations, etc. They also present the Statement of Work and the Technical Requirements Document, which define the requirements for the development of the flight-ready prototypes including the expected deliverables for each design review.

The project is evaluated through 4 formal design reviews: the Requirement Review (RR), the Concept Review (CR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). This recalls the aerospace product development control process, which guides the organisation of large engineering teams presented in chapter 1. During these meetings, the students are required to submit a detailed report and to formally present the work to the industrial partners who will assess the progress and approve important issues, in collaboration with the teaching staff coaching the project team.

During the first three weeks, the students have to prepare the RR. This involves: reading the documentation, detecting missing or conflicting information and data, and deciding how to organize the team to produce the new pylon. At the RR, the students must present a schedule for the entire project, a detailed planning of the engineering activities up to the CR, the team organization to fulfil the tasks, and a draft of the cost management plan.

For the CR, the students have to present the various concepts explored with their advantages and disadvantages, their final solution selection process with a detail of the evaluation criteria, a risk assessment plan which identifies the major risks and their mitigation, and any adjustments made to the project schedule or budget.

In the second semester, the adopted solution is presented at the PDR. A first estimation of the product cost and weight is made and analyses of critical parts and systems are presented. A configuration methodology must also be discussed with the partners. At the end of the second semester, the final report and a prototype of the structural elements of the new pylon are presented at the CDR.

Over the last two years, the CDR presentation has taken place at one of the industrial sites. In the morning, the detailed design is reviewed for three hours. In the afternoon, an executive version of the project is presented to senior management staff of the participating aerospace companies. This new event was an ideal opportunity for the author to gather feedback from senior engineers on the level of similarity between these student design reviews and industrial practices.

The monitoring of this project resulted in the acquisition of a set of 4 design reviews, from the RR to the CDR. These were all videotaped and a complete archive of all the documentation generated during the project was also kept. The CAMAQ project provided valuable analytical data and a setting where the three research cycles described in chapter 1 could take place. The tools and techniques used for the analysis of this case study were trialled by some of the participants to complete the "interact" cycle (chapter 1). This case study enabled the elaboration of several Meeting Capture Templates (MCT) presented in section 3 of this chapter. The video recordings were also used to test the Quindi Meeting Companion technology described in chapter 3 (§4.2).

To measure the level of professionalism with which the students performed, a short questionnaire was circulated amongst the experts (industrial supervisors and CDR observers) who participated in the CAMAQ project. To summarise the overall impression which filters through the results of this survey, the following comments made by some of the respondents illustrate just how closely to industrial practices the student team performed:

> *"My detailed involvement was mainly with the Certification Plan, and it was representative of a real industrial project. Equally the PDR and CDR presentations were comparable with industrial practices."*

> *"(...) As a design reviewer I want to see what idea's you have examined, what depth they have been investigated, where you are making high risk assumptions and to what extent the design is extrapolated from current practice (technical risk again). In general by CDR the student teams have exhibited behaviour comparable to top class aerospace design organizations in terms of the relevancy of the material presented."*

"The major difference would be the depth to which the proposed solution is evaluated. In industry a design review typically takes in the order of a week or more."

"I believe the students get a much broader visibility of an entire engineering project from CAMAQ than they would in an internship. In fact, the partners have to keep reminding the students that their initial years in industry upon graduation will not give them the broad sweep visibility of a programme in the way that the CAMAQ project does."

There was also a very interesting comment made by one of the industrial supervisors concerning differences between design reviews held at different levels of the product structure in industry (i.e. a design review at a major assembly level versus a design review at a component level):

"(...) reviews are adapted to the program phase which they address. A concept review may emphasize overall configuration and technology requirements to determine what is necessary to put into a technology development program for risk mitigation. A PDR may spend more time on the completeness of requirements prior to entering details design where the big money starts to be spent. A CDR tends to look more at the design to be committed to production to ensure that it will be producible and may also address how things are substantiated for certification to address any gaps between the two. Reviews may be at product, module, component, or part level as required and may involve a large program style presentation or a simple round table review with other designers. In general the guiding principle is that the review must provide objectivity by having other than the original designer and program personnel in the review team and there should be evidence (meeting minutes, action lists) on record of the review having taken place."

Based on this comment, it is important to highlight that the case studies used for the research presented in this thesis cover design reviews from part level (e.g. Airbus UK PDR) to module level (e.g. CAMAQ project). The monitoring of a product level design review was not offered by Airbus UK for obvious confidentiality reasons.

2. THE TRANSCRIPT CODING SCHEME (TCS)

Before attempting to analyse meeting transcripts it is of great importance to adopt a coherent methodology that can be applied in a systematic way to recordings of design meetings. The essential part of creating this methodology is to determine the criteria under which transcripts will be analysed. It is now essential to present the Transcript Coding Scheme (TCS), necessary to an organised, structured and systematic coding methodology for meeting transcripts, based on the two meeting models outlined in chapter 3. Robillard *et al.* (1998) and Garcia *et al.* (2003), cited previously in chapter 3, detail clear and reproducible methods for coding interventions and the TCS is largely formatted along the same guidelines. The TCS is built around a structured transcript which uses specific transcription conventions and 8 codification elements. The TCS was applied for both case studies recorded at Airbus UK. The complete transcript and coding for the Airbus UK RR is available in appendix A, and the complete transcript and coding for the Airbus UK PDR is available in appendix C.

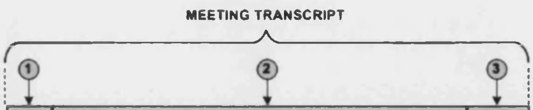
The transcribing and coding process described in the following sections are part of a qualitative research approach to discourse analysis. In fact, the whole process and the results from the TCS methodology, which will be discussed later in chapter 5, implicitly follow certain guidelines prescribed by "grounded theory" practitioners in the field of sociology (Corbin and Strauss 1990). Indeed, as mentioned previously, the TCS approach is a systematic methodology where the results generate theory from data. The interpretation of the results is based on an explicit and reproducible coding of the event under study (design reviews) and the overall aim of the TCS approach was directed towards answering the following questions (see chapter 1, §2.3):

- What types of communication and information processes occur during meetings?
- How is it possible to analyse design discourse?
- What is a meeting? What characterises a design review and the transactions that take place there?

In this chapter, the following sections will therefore provide all the necessary information on how the TCS was built and on the underlying intent of each criteria that composes the coding scheme.

2.1. DTM Transcript conventions

As suggested in chapter 3, transcribing is a task repeatedly used in social sciences and linguistics but has not warranted the development of official and standardised conventions. The first step was therefore to define a set of transcribing conventions for the purpose of this research. The conventions adopted were more basic than those mentioned in chapter 3 (§1.1): for example no intonation or accentuation coding was necessary. Each transcribed intervention is preceded by the name of the speaker and the time at which the utterance ended. Figure 4.3 illustrates the composition of the meeting transcription approach.



ID	TRANSCRIPT	TIME
GH	We used 3 sections // and optimised the path through the pylon	00:10:03
SJC	/Good/ I see you used standard fittings to join all the elements	00:10:06
CAM	What about the pressure loss? Did you do any calculations?	00:10:08
[GH]	[ ]= audio not understood	00:10:11
CAM	Ah! OK. sorry ... so can you explain how you achieved this?	00:10:16

LEGEND

1- IDENTITY OF THE SPEAKER (initials);

2- TEXT TRANSCRIBING SPEECH (see transcript conventions below);

3- TIME WHEN THE INTERVENTION ENDED (hours:minutes:seconds);

TRANSCRIPT CONVENTIONS

Specific textual conventions:
- Words in ***Italic*** in the text mean that they have been transcribed approximately
- The words transcribed between the slashes, i.e. ***/ words /***, overlap words from the previous or following interventions which are also between slashes
- The double slash, i.e. ***//***, shows an interjection from the following speaker without overlap
- **...** in the text marks a pause in the speech (less than 10 seconds)
- **(...)** in the text marks a pause in the speech (over 10 seconds)
- **[...]** in the text marks a pause in the audio (over 30 seconds)

Specific time conventions:
- ***(...)*** in the text marks a non transcribed part (over 10 seconds)
- ***[...]*** in the text marks a non transcribed part (over 30 seconds)

Specific speaker conventions:
- **[speaker ID]** means that the intervention from that specific speaker was not transcribed and the reason is given in associated the text column
- If *Speaker ID* = **X**, then the speaker was not recognised by the transcriber

Figure 4.3 *Transcript conventions for the DTM case studies (note: the interventions used in the extract are fictional)*

A transcript therefore presents itself in a table format to facilitate the coding process, which will be described in the following paragraph.

2.2. The final TCS

As shown in figure 4.4, the TCS table is constituted of the meeting transcript table followed by a number of coding columns used for in-depth analysis purposes. The format of this analytical tool is essentially a table, where each row is an intervention made by one of the participants. In the coding scheme, the interventions can then be grouped by exchanges. The size of exchanges, in number of interventions, varies according to the coding intent; 8 coding elements, detailed in figure 4.4, are tracked by the TCS.

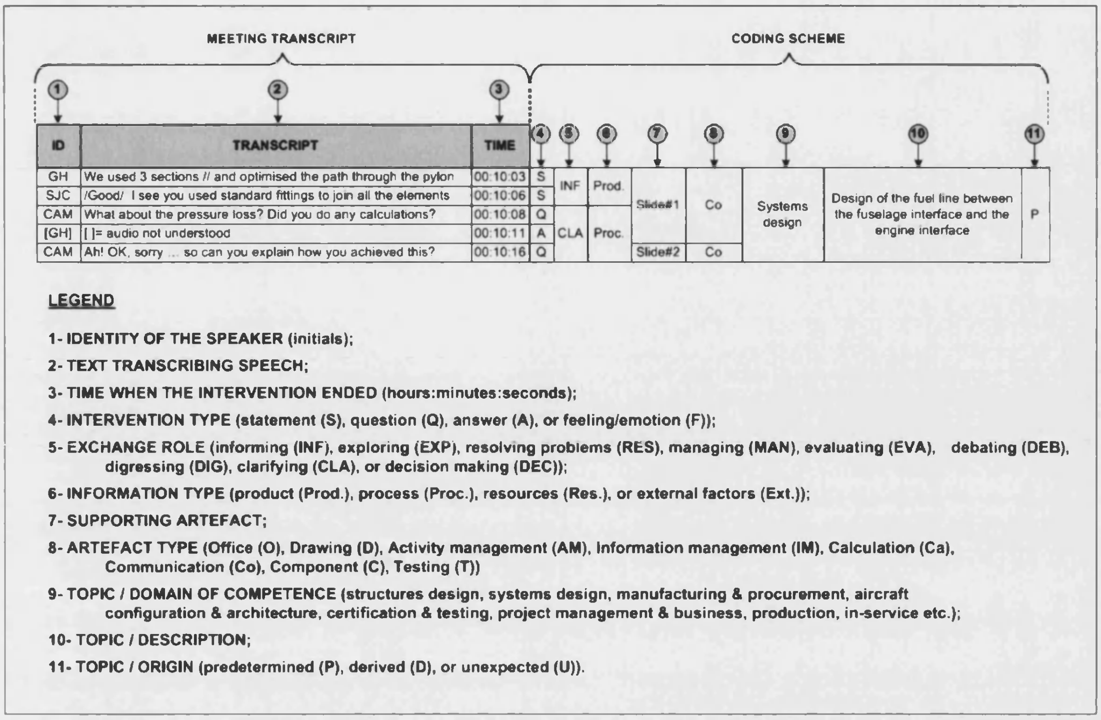


Figure 4.4 *Illustration and explanation of the Transcript Coding Scheme (note: the interventions used in this extract are fictional)*

Most of the coding elements have been directly adapted from the two meeting models detailed in chapter 3. To complete the review of the TCS, table 4.2 outlines the research objectives for each coding element and shows how this analytical tool can offer a qualitative and structured insight into the contents and communication mechanisms of a meeting.

It is important to give more detail on the "intervention" and "exchange role" coding. The general intent of these two crucial coding elements has been discussed in chapter 3 (§2.1) in the context of the object-oriented classification scheme. Four main intervention types have been identified in this model along with their shorthand which is used in the analysis of the transcripts: Statement (shorthand: S); Question (shorthand: Q); Answer (shorthand: A); Feeling or emotion (shorthand: F).

The first three intervention types are defined by their natural use in English language and it is therefore not necessary to specify them.

However the 'feeling or emotion' intervention type is more ambiguous; it has been used to code interventions which convey a state of awareness, an opinion based on emotion, or a general impression conveyed by the discussion or artefacts, i.e. "*Really?!*"; "*Good*"; "*Oh, seriously?*".

Table 4.2 Summary of the research objectives for each coding element in the TCS

Ref. in figure 4.4	Name of the coding element	Research objectives
4	Intervention type	The intervention is the basic unit used to segment the transcript. The four types of interventions used in the TCS (statement, question, answer, or feeling) can help characterise typical spoken discourse patterns. These observations are commonly outlined in the research field of linguistics and used to develop semantic search tools.
5	Exchange role	Interventions can be grouped into exchanges. The 9 exchange roles defined in this research (see legend in figure 4.4) help to get a precise picture of the overall role of the meeting, or even of specific portions of the transcript. The results can also be used to illustrate the respective importance and influence of the generic design review activities as defined in the 2 models proposed in chapter 3, section 2.
6	Information type	This coding element relates to the types of product life-cycle information: product, process, resources, or external factors (chapter 2, §3.3). The results from this analysis could help understand correlations between the type of design review and the type of information exchanged.
7	Supporting artefact	It is important to track the artefacts used to support the conversations (chapter 3, §3.2). The artefacts can be informal communication support elements (sketches, annotations, presentation slides) or even input documents submitted before the meeting. This coding element will provide quantifiable data to evaluate how much of the conversations of a design review are supported by artefacts.
8	Artefact type	Evaluating and quantifying the types of artefacts used during design meetings, based on the categories proposed in chapter 3 (§3.2), can be useful to develop meeting capture and facilitation tools that support the integration of artefacts in meeting records. "Specialised" categories will be preferred to "inclusive" ones (chapter 3, §3.2) when both are applicable.
9	Topic – domain of competence	These 3 coding elements track the topic of discussion from different perspectives. The domain of competence and the more precise description of the topic will reflect the nature of the contents discussed during the design reviews. The origin of the topic (predetermined, derived, or unexpected) will reflect, to some extent, the level of structure of the meeting. Coupled with the measure of "digressing" (exchange role) this will provide a good insight into how formal and structured design reviews are.
10	Topic – description	
11	Topic – origin	

Nine exchange roles have also been outlined in the object-oriented meeting model. Some of these roles have been taken from previous literature on the topic of meeting analysis presented in chapter 3. Table 4.3 lists the exchange roles used in the TCS analysis, and provides a brief description for each one.

Table 4.3 Description of the exchange roles used in the TCS

Exchange role	Shorthand coding	Description
Clarifying	CLA	Questions and answers where someone either asked or seemed to misunderstand. Clarifications serve to clear up misunderstandings from other individuals (Olson *et al.* 1996).
Debating	DEB	Discussion engaging argumentation through opposite views and where evaluation criteria can be proposed
Decision making	DEC	Discussion leading to a collective consensus over a debated issue or to a final verdict based on prior evaluation of options.
Digressing	DIG	Members joking, discussion side topics, or interruptions having to do with things outside the meeting (Olson *et al.* 1996).
Evaluating	EVA	Interventions where judgments and estimates are made on issues concerning the topic of discussion.
Exploring	EXP	Discussion takes place towards the investigation or examination of various possibilities before evaluating, debating or decision making.
Informing	INF	Discourse in which pieces of information relevant to the topics of the meeting are shared. Informing can often lead to a need of clarification by other participants but it is not intended to present debatable issues.
Managing	MAN	Discussion having to do with activity not directly related to the content of the design or having to do with the orchestration of the meeting (Olson *et al.* 1996).
Resolving problems	RES	A problem is raised and the solution is elaborated without debate.

2.3. Evolution and limitations of the TCS

The TCS went through an iterative validation process before the stabilised final version, presented in figure 4.4, could be established. The evolution of the TCS was guided by a number of factors: the relevance and interpretability of the coding element, and the reproducibility of the coding intent. The main transformations involved the coding of the topic (coding reference 9, 10, and 11 in table 4.2) and the refinement of the artefact coding. The final TCS also saw the inclusion of the "information type" analysis. This coding element could provide useful insights into selecting appropriate information modelling and knowledge capture techniques in the specific case of design reviews.

Initially, the "topic tracking" elements tried to codify the contents of the conversations with 3 levels of specification:

- Generic level, with the attributes: design; manufacture; management.
- Specialisation level, with the attributes: design; manufacture; management; product; process; function; feature; meeting; project; team; organisation; performance.

- Knowledge tracking level, with the attributes: solution; rationale; experience.

This approach, which aimed at simultaneously evaluating the generic content and tracking key knowledge elements in a transcript, failed to provide a consistent and reproducible method to categorise the contents of the spoken discourse. Only the "generic level" managed to produce coherent results, while the "specialisation level" was confusing and the "knowledge tracking level" was simply not suited to the transcript break-up into interventions and exchanges.

This last point was a significant issue and led to the elaboration of a separate methodology to track key knowledge elements in the transcripts – the Information Mapping Technique (IMT) – presented in section 4 of this chapter. Also, the time necessary to complete the TCS, including the transcribing process, does not make this tool appealing for more practical meeting capture applications. Nonetheless, it remains a thorough and comprehensive research strategy to understand the design transactions which take place during a meeting based on the transcribed account of the event; this will be illustrated by the results discussed in chapter 5.

3. THE MEETING CAPTURE TEMPLATES (MCT)

As suggested previously, the need to develop a simplified approach to the TCS, where the data could be collected as the meeting is taking place, emerged as an important issue for this research project. This led to the creation of Meeting Capture Templates (MCT) that were used and perfected during the CAMAQ project case study. Because of the strong and very apparent links with the TCS, the MCT can also be generally considered as a tool used to generate theory from data. The research goals are similar as the ones outlined in section 2 for the TCS, but because of the pragmatic approach that was used to develop this research tool, the MCT has also gone some way into investigating the following fundamental research question guiding this thesis: *what are the available means to capture information during meetings?* The use of the MCT has therefore helped the author to forward practical insights into information capture during meetings, discussed later in chapter 6.

3.1. Description of the MCT

An MCT presents itself as a table, where each row is numbered and corresponds to an entry used by the minute taker during the meeting. Figure 4.5 shows an extract of a blank paper-based MCT featuring the first 3 rows; this is the final version developed by the author.

#	Topic (in a few words) and Action (+ name, date)	Who?	What?		Impact on design and manufacture?	Time
1		☐ Struct ☐ Sys	☐ Exploring	☐ Clarifying	☐ Process	
		☐ Certif ☐ Magt	☐ Evaluating	☐ Decision	☐ Product	
	Action	☐ Manuf ☐ Client	☐ Debating	☐ Informing	☐ Tools	
2		☐ Struct ☐ Sys	☐ Exploring	☐ Clarifying	☐ Process	
		☐ Certif ☐ Magt	☐ Evaluating	☐ Decision	☐ Product	
	Action	☐ Manuf ☐ Client	☐ Debating	☐ Informing	☐ Tools	
3		☐ Struct ☐ Sys	☐ Exploring	☐ Clarifying	☐ Process	
		☐ Certif ☐ Magt	☐ Evaluating	☐ Decision	☐ Product	
	Action	☐ Manuf ☐ Client	☐ Debating	☐ Informing	☐ Tools	

Figure 4.5 *The final version of the Meeting Capture Template used during the CAMAQ case study*

The second column of the MCT, "topics and actions", provides space for the observer to make a few notes, using his own words to describe the conversation topic and the related actions. Each row in the MCT therefore corresponds to a new conversation topic. The "who" column helps the minute taker to quickly track the involved parties in the conversation. The "what" column is a simplification of the exchange roles found in the TCS; here, only 6 core exchange roles were kept (exploring, decision making, evaluating, clarifying, informing, and debating) based on the experience gained from the TCS results using the Airbus UK case studies and the previous MCT developed for the CAMAQ project. The "information type" coding element in the TCS has been simplified here in the "impact" column, where each conversation topic can be tagged according to whether it has an impact on the product, the process, or the engineering tools used by the students (resources). Finally, the "time" column enabled the user to mark the approximate time at which each entry was made in the MCT. This was ultimately used to synchronise the various entries of a MCT and compile the results when several users were involved in the validation process.

Most of the columns are derived from the TCS, but have been formulated with a more comprehensive terminology. This was a necessity as the finalised MCT presented here went through an intensive validation process, involving the students working on the project. During each design review, 3 to 4 students were chosen to use the MCT in order to help capture the minutes of their meetings and provide analytical data for the research.

Their feedback helped to enhance the MCT and draw guidelines for the development of minute taking templates to be used in the industry.

3.2. Evolution of the MCT

The MCT presented previously went through three major versions. The first version was a direct simplification of the TCS based on what the author believed could be tracked on the fly by a trained minute taker. The second version was very close to the one presented in figure 4.5, but contained a few minor aspects which were modified in this third and final version. Illustrations of these two early versions of the MCT are available in appendix E along with the tables of results generated from the CAMAQ project case study.

In the first version, the "exchange roles" coding was simplified in the MCT based on the results obtained in the TCS analysis. Three exchange roles were left aside: "Digressions" as they occurred very rarely during the design reviews monitored, "Resolving problems" because they were often confused with "debates", and "managing" as this exchange role can easily be traced by other coding elements such as the topic and the participant's role.

The second version saw the addition of a more specific classification of the participants involved and a dedicated space to note the actions related to the topic of interest. The new participant classification was a direct consequence of the observations made on the usability of the previous template; users were effectively very comfortable with the multiple-choices boxes offered in the "who", "what", and "impact" columns, and the "who" column was therefore expanded to provide more information on the participants involved in the conversation. Also, at the request of most of the students involved in the development of the MCT, extra space was included in the "topic" column to provide means to capture the actions associated to each topic.

This last point can be seen as a move from an analytical tool towards a capture template. Indeed, two research and development objectives were hidden behind the MCT: the simplification of the TCS to enable the analysis of design reviews on the fly, and the progressive evaluation of templates to capture the content of meetings in a structured and reusable format. The results related to the use of the MCT in the CAMAQ project case study will be reported in chapter 5. In chapter 6, however, the experience gathered from the use of the MCT will foster practical proposals for the elaboration of knowledge-oriented meeting capture tools and techniques, notably a specific "design review capture template".

4. THE INFORMATION MAPPING TECHNIQUE (IMT)

The idea of an information mapping technique to measure the knowledge loss was effectively inspired from the work carried out by Hoffmann (1980). His quest for a suitable definition of the term "information" led to a comparative study of textual documents and their abstracts. Analysis of the material was based on a graphical representation of the information content. Statements were highlighted in the text, numbered and then mapped out using conceptual interrelationships found in the original text. Measures produced were based on the value of the facts or statements depicted as nodes in the diagrams. The value of a node was given by the number of conceptual connections it possessed (i.e. the higher the number of links to a node the more important the node was). It is not the intention of this research to evaluate the whole information content of the documents; this section will introduce an alternative approach, the Information Mapping Technique (IMT), developed by the author and which focuses on the occurrence of 4 specific knowledge concepts reviewed in chapter 2: decisions, actions, rationale, and lessons learnt. The IMT is therefore based on the comparison of two types of documents: the transcripts and the minutes of meetings. The results enable a simple but effective visualisation of the contents of a document according to the 4 aforementioned knowledge elements centred on the main topics of discussion.

This research approach was effectively used by the author to answer the following fundamental research question outlined in chapter 1 (§2.3): *what are the important knowledge elements that are not currently captured during design reviews?* Indeed, the TCS did not offer the right setting to efficiently track these 4 key knowledge elements. The IMT was ultimately used to track these elements, while also providing means to qualitatively and quantitatively measure knowledge loss between a meeting (based on its transcript) and its formal historical record (the minutes). The complete results of the knowledge loss study are available in appendix F, and will be further discussed and analysed in chapter 5.

4.1. Description of the technique

In simple terms, each knowledge element found in the text is represented by a symbol in an information map. The symbols are clustered around focal points: the main meeting topics. The result therefore presents itself as a succession of network graphs centred and sequenced following the different focuses of the event as shown in figure 4.6.

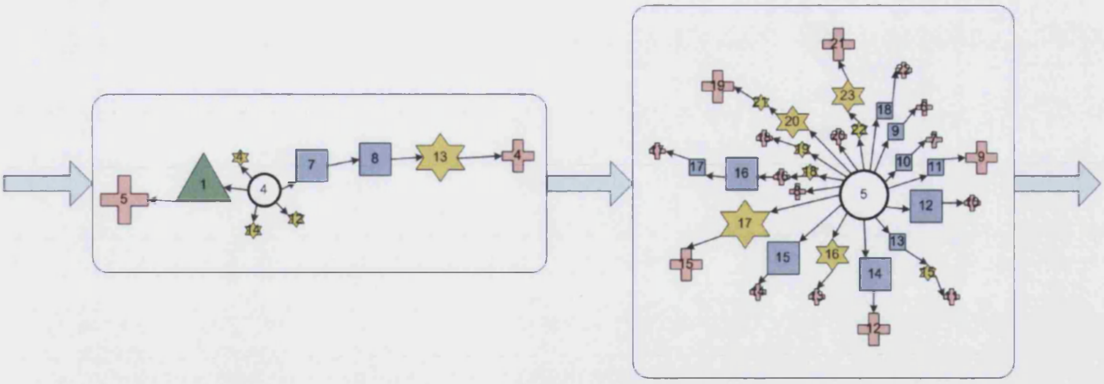


Figure 4.6 *An extract of the information map for the minutes of a design review*

To produce these information maps, 2 stages must be followed: the encoding and the mapping of the document. To encode a document, each knowledge element (decision, action, rationale, or lesson learnt) must first be highlighted in the original text and summarised in a register table according to its type. Figure 4.7 presents an extract of an "action elements" register to illustrate such tables. The main topics of the document are also listed in a distinct register table and the encoding therefore involves the creation of 5 separate registers. Other details such as the number of words and the subsequent coding size are also recorded in the tables.

Actions			
#	***Summary***	***N° of words***	***Coding size***
1	Include quantity in the Equipment Specification	15	1
2	Clarify and confirm the top-level requirement for the deletion	35	2

Figure 4.7 *Example of the structure of a register table for action elements*

Then, for the information mapping, each row in each table is represented in the graph by a symbol specific to its knowledge type and a number that relates it directly to its register row number. Figure 4.8 illustrates the coding scheme for the symbols. The size of the symbol reflects the volume in number of words of each information item and is relative to the overall size of the document.

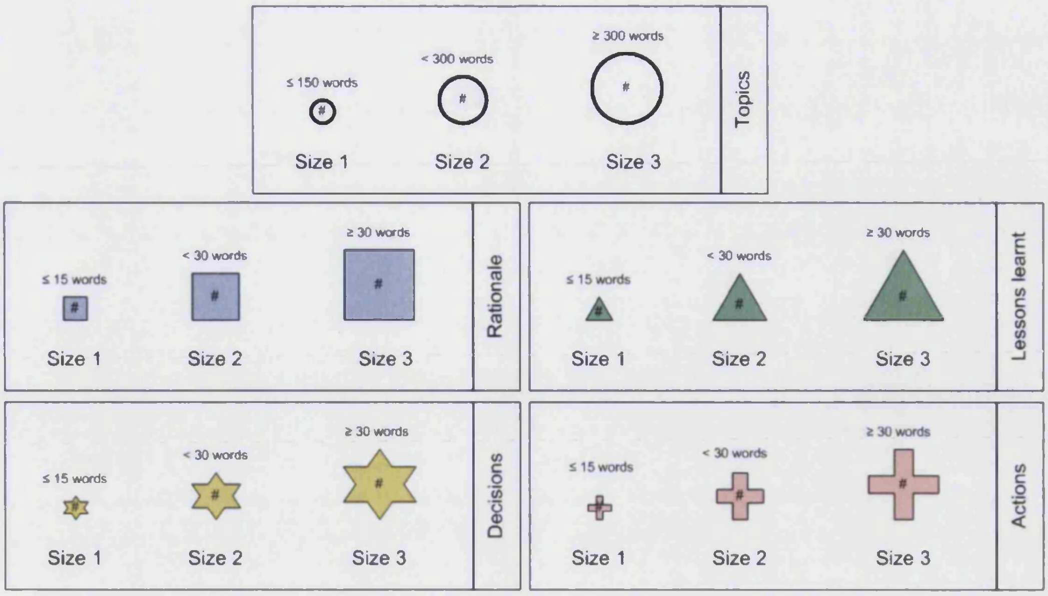


Figure 4.8 *Example of the information mapping coding scheme used to map the minutes of the Airbus UK RR*

To finalise the mapping, the topics are used as focal points and the items are connected around them in "threads" using the conceptual relations inferred by the text, as previously illustrated in figure 4.6.

4.2. Knowledge evaluation criteria

The IMT has developed and explored a graphical approach, which effectively measures the knowledge lost between a crucial design management activity, the design review, and its official record. To complete the review of the IMT, 4 knowledge evaluation criteria have been established and are listed below:

- *Volume:* refers to the specific number of words used to express any of the knowledge entities or topics and is visually acknowledged by the coding size of an element.
- *Length* is determined by the number of elements in a thread. Combining this and the previous criterion helps to express the importance of a topic, knowledge element, or thread relative to the rest of the document.
- *Variety:* this criterion reveals the level of richness of a thread. A rich thread will therefore have a variety of explanations and outcomes.

- *Order/Sequence:* analysing the *order* in which the four knowledge elements appear in a thread could give an insight on how threads are typically formulated. With more data, typical patterns would appear.

This methodology has unveiled a range of properties which can be used as comparative criteria, and the Requirement Review recorded at Airbus UK will illustrate these proposals in chapter 5. The work presented in this thesis focuses essentially on organisational knowledge loss, but information mapping is thought to have much more to offer in the field of design research. A new form of design rationale representation could be developed and a further study of this technique could give practical insights into alternative minutes archiving strategies.

CHAPTER SUMMARY

The fundamental research activity reported in this thesis is the monitoring of engineering teams working in design review situations. Three case studies were organised to this effect; two of them took place in an academic setting, while the Airbus UK case study provided this research with the opportunity to observe design reviews involving practicing aerospace engineers working in their natural environment.

The first case study, the observation of a student team working on a design project at the University of Bath, was used to test recording equipment and to start developing a monitoring strategy. The two design reviews recorded during the Airbus UK case study were completely transcribed by the author for detailed analysis purposes. Finally, the CAMAQ project (the second academic case study), involving a team of graduate students supervised by industrial experts, resulted in the video recording of the four design reviews (RR, CR, PDR, and CDR) used to control the design stages of the product development process. This last case study also permitted to test the meeting analysis and capture tools developed by the author. Based on the formal understanding of design meeting mechanisms discussed in chapter 3, a unique set of tools and methods were used to analyse and characterise design reviews: a Transcript Coding Scheme (TCS), Meeting Capture Templates (MCT), and an Information Mapping Technique (IMT).

The TCS enables to analyse in depth meeting transcripts, which are documents typically used by a number of research domains in the study of spoken discourse. In the context of the DTM research, a specific coding scheme was adopted to produce measures according to a number of research criteria: roles of the participants, intervention types, exchange roles, information types, artefact types, domains of competence involved, origin of the topics of discussion. The results from the coded transcripts yielded a number of interesting results concerning information and communication processes observed during the Airbus UK case study, these will be reported in the next chapter. Ultimately, the TCS tables that include the transcript and its coding were at the basis of the development of two other tools, the MCT and the IMT, which fulfil specific needs left out by the TCS.

A Meeting Capture Template (MCT) enables the user to code the meeting as it is happening, effectively bypassing the transcribing process imposed by the TCS. An MCT presents itself as a table where each entry (or line) corresponds to a new conversation topic. Each entry can then be coded directly by the user; the columns of the MCT relate to a coding criteria derived from the TCS. An MCT can be used to analyse a design meeting according to the following aspects: participant role, exchange roles, information types, and topics of discussions (with their associated actions). The MCT was successfully trialled and developed during the CAMAQ project case study; the data captured with the MCT during the CAMAQ project is analysed in the next chapter along with the results from the TCS.

The Information Mapping Technique (IMT) was specifically developed to measure levels of knowledge loss from design reviews based on the comparison of two documents: the minutes and the transcript of the meeting. The IMT is therefore text-based and requires the user to single out specific information entities in the document under consideration. These information entities are the expression of key knowledge elements – rationale, decisions, lessons learnt, and actions – described in chapter 2 as essential to capture for both the project's and the company's memory. The information entities are then associated to a specific symbol according to their knowledge type and these are mapped out in a succession of network graphs which follow the topic thread proposed by the document. The IMT was used to map the information present in the minutes and in the transcript of the Requirement Review from the Airbus UK case study. The results, which will be discussed in chapter 5, illustrate the levels of knowledge loss in minutes of meetings and have fostered a number of empirical hypotheses to counter this problem.

The analytical tools described in this chapter have been used to help interpret the empirical data generated from the different case studies. These results will complement and refine the theoretical findings on design reviews, discussed in the previous chapters. The development and use of the TCS, MCT, and IMT has also stimulated the elaboration of a strategy to improve the efficiency of meeting capture practices. This perspective will be described later in chapter 6.

CHAPTER 5

RESULTS FROM THE DTM CASE STUDIES

This chapter presents the results collected from the DTM case studies according to three analytical perspectives: the communication processes observed, the information processes detected, and the knowledge lost from the meeting records. The relevant data was extracted from the recorded case studies using the three meeting analysis tools presented in chapter 4. The Airbus UK design reviews were analysed with the Transcript Coding Scheme (TCS) and the Information Mapping Technique (IMT), while the CAMAQ project design reviews were studied using the Meeting Capture Template. The graphs and charts presented in this chapter illustrate the considerable range of analytical capabilities offered by the meeting tools developed for the purpose of this research. The results and the way they have been organised in this chapter constitute an original and conclusive strategy to analyse in depth design meeting transactions.

1. PRELIMINARY REMARKS ON THE DATA FROM THE DTM CASE STUDIES

Before presenting the results from the DTM case studies, this section will briefly outline the practical aspects regarding the compilation and manipulation of the data generated by the three tools described in chapter 4.

1.1. Data from the Transcript Coding Scheme

The TCS was used to analyse in depth two design reviews: the Airbus UK Requirement Review (RR) and the Airbus UK Preliminary Design Review (PDR). The complete transcripts and coding are available in appendix A for the RR and in appendix C for the PDR. The supporting data tables which were necessary to build the illustrative graphs and charts presented in the following sections were compiled respectively in appendix B for the RR and appendix D for the PDR.

Most of the results derived from the TCS are expressed in time units or percentage of time units. The notion of time in the TCS relates to the time of transcribed speech; some interventions were not taken into account for practical reasons, such as poor audio quality or pauses in the meeting. Moreover, certain coding elements, i.e. the "intervention type", the "speaker ID", and the "artefact type", were more appropriately analysed with a simple count of their occurrences in the TCS.

The results from the TCS were illustrated using pie charts, and a number of different bar charts (simple bar charts, grouped bar charts, subdivided bar charts, and subdivided 100% bar charts). Each one of these graphical representations was selected by the author to best suite the visual communication intent of the corresponding analysis. Finally, passages of the actual transcripts have also been used to support certain statements made in this chapter.

1.2. Data from the Meeting Capture Template

The MCT was used to collect data from the four CAMAQ project design reviews. Several participating students helped to complete the MCT during each meeting and the data presented in appendix E is a compilation of these paper-based forms.

The CAMAQ design reviews were videotaped, which enabled the author to adjust old MCT versions to the final one presented in chapter 4, and maintain a certain level of consistency in the results throughout the project. A scanned page of each one of the two preliminary versions of the MCT, discussed in chapter 4, is also presented for illustrative purposes in appendix E.

The videotapes also provided an efficient means to evaluate, post-meeting, the approximate duration of each entry in the MCT. The results shown for the CAMAQ design reviews are therefore time-based. In the following sections, the CAMAQ project data has essentially been used to illustrate trends across the life of a design project; in this case, the author favoured the use of bar charts, grouped bar charts, subdivided 100% bar charts, and rectilinear line charts (2D and 3D) to represent the data.

1.3. Data from the Information Mapping Technique

The IMT was only performed on the Airbus UK RR. The main reason for this was the high quality of the transcript; indeed, only 1% of the total meeting time could not be transcribed. The minutes of the meeting were completely mapped with the IMT, while only the critical topics in the transcript were mapped. All the reference tables, mapping coding schemes and information maps produced from the RR (minutes and transcript) have been grouped in appendix F. The initial document mark-up of the minutes and the transcript have not been included in this thesis. Instead, illustrative examples are provided in §4.2.1.

The IMT results present themselves as a succession of network graphs centred and sequenced following the different focuses of the event as described in chapter 4.

2. DESIGN REVIEWS FROM A COMMUNICATION PROCESS PERSPECTIVE

A number of concepts related to communication processes in engineering design have been introduced in chapter 2. With the results from the case studies, it is now possible to outline specific communication characteristics of aerospace design reviews. This section will analyse some of the results based on the TCS, used for the Airbus UK case study, and on the MCT, used for the CAMAQ project case study.

The comments and analyses have been grouped according to 2 specific analytical dimensions observed: the structure and the intent of the communication processes. Finally, the characterisation of decision making communication patterns offers a practical insight into the analytical potential of the TCS.

2.1. Communication structure

The structure of the communication processes involved in a meeting can be viewed at various levels of detail; from the event as a whole down to the intervention level, the basic unit of discourse analysis used in this research as discussed in chapter 3 (§2.1).

Observing the overall meeting roles involved in the spoken discourse reveals important aspects in the organisation of communication processes. These can of course be related to generic communication models presented in chapter 2. Figures 5.1 and 5.2 illustrate the influence of each generic meeting role on the conversations, and the variety of configurations that can occur in a design review situation. The values are based on an account of the "speaker ID" coding criteria provided by the TCS. For both pie charts, portions in dark grey indicate the participants who took position in the review team, while portions in light grey mark participants who where part of the project team.

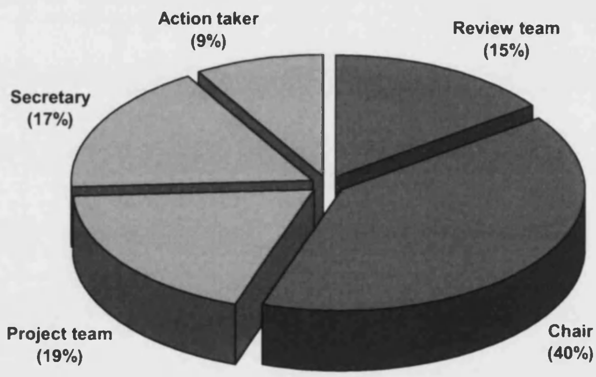


Figure 5.1 *Percentage of conversation time per meeting role during the Airbus UK RR*

In the case of the RR (figure 5.1 above), the meeting was internal to Airbus UK and the chair person drove the entire meeting to make sure that the requirements established by the project team were consistent and coherent before they could be sent off to the supplier. The secretary was a junior engineer and was the main respondent for the project team; he was actually responsible for the documents under review and, because of this situation, another participant helped the secretary to take note of the actions. The secretary was only in charge of writing the minutes, with most of the actions bearing his name as "actionee". The overall proportion of conversations made by both parties is fairly balanced (55% for the review team and 45% for the project team); this seems to be related to the communication configuration where all the participants were sat round a table to discuss the issues pointed out by the chair person.

In the PDR (figure 5.2 below), the meeting configuration was very different: the supplier was represented by a chief engineer who made a formal presentation of the design achievements to the Airbus UK review team. This explains the dominance of the project team, effectively embodied in a single participant, in the overall communication distribution per meeting role. In this case, the chair person simply managed the meeting and the secretary took on the role of reviewer and action taker. The PDR was representative of a design review with a supplier involved.

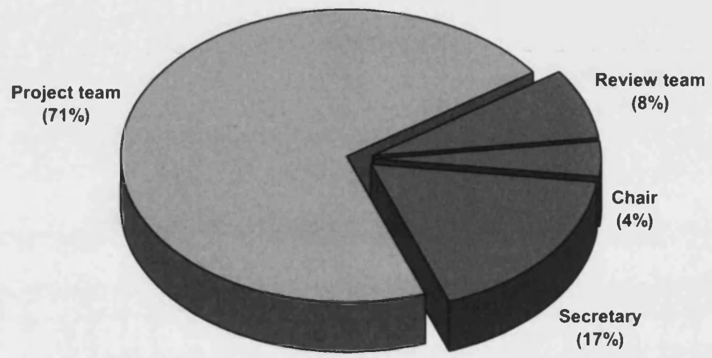


Figure 5.2 *Percentage of conversation time per meeting role during the Airbus UK PDR*

Although the MCT used to analyse the CAMAQ project design reviews is not as precise as the TCS, it was nonetheless possible to determine a precise estimation of the meeting role configuration over the 4 design reviews monitored, as shown in figure 5.3.

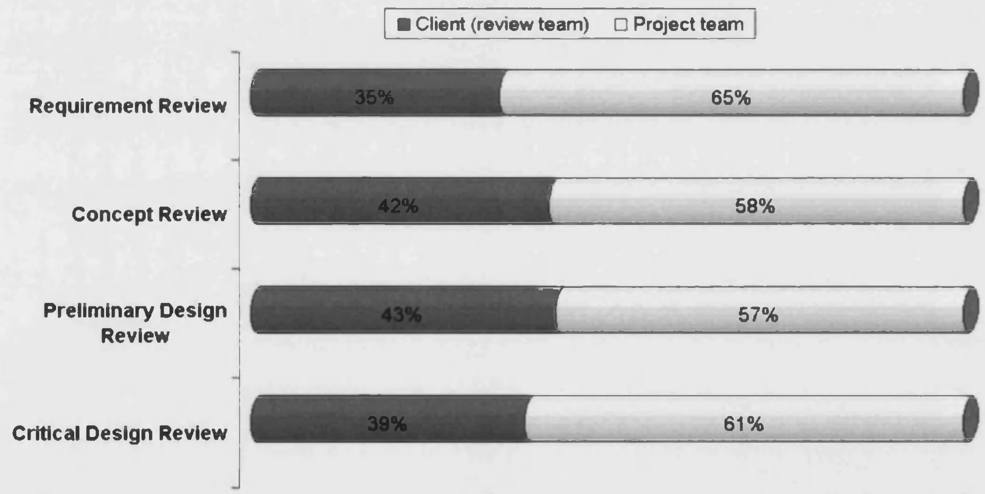


Figure 5.3 *Participants' involvement in the CAMAQ project design reviews per meeting role (% conversation time)*

The results confirm the characteristics highlighted in the Airbus UK PDR case study where a supplier was involved; in these situations, most of the conversation time is taken up by the design project team (the supplier). The values for the review team (client) in the

CAMAQ project case study are slightly higher than those observed for the Airbus UK PDR: this can easily be explained by the fact that the industrial supervisors needed to evaluate both the design and the students.

In general, the communication structure outlined by these trends in speech time per meeting role can be explained by certain formal communication scenarios referred to as "interface negotiation" discussions (see chapter 2, §2.2), namely:

- "Justifications"; the project team formally presents the design achievement to the review panel, e.g. most of the meeting time during the Airbus UK PDR was spent by the supplier to present and justify the design choices made.
- "Information requests"; the review team asks for more information from the project team, e.g. see passage 1 below from the Airbus UK RR transcript

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Passage 1: from the Airbus RR transcript (between 02:09:31 and 02:10:30):

"Where is the process defined ... for reviewing the risks, what are you using?"

"This risk register sheet ...I didn't know if there was ... "

"It's about our RCPD process that we manage risks, it's part of the airbus UK policy that we manage risks"

"Absolutely, there's a definition on the 380"

"Yeah is there a document in there for risk management?"

"... It's probably about 3 pages, the one I'm thinking of anyway. Which is the process, procedure of ensuring that they are reviewed and that they are handled ...I can think of the one for 400M and that's only a couple of pages"

"Ok I'll try and get that"

The "intervention" coding element in the TCS also provides insights into the detailed structure of speech in a meeting situation. Although this type of analysis is not really the main focus of this research, it has nonetheless helped to outline interesting aspects and trends of spoken discourse in the context of aerospace design reviews. Even though the TCS was only used for 2 meetings, the Airbus UK case study generated more than 1000 transcribed interventions. Figures 5.4 and 5.5 therefore show the distribution of the 4 intervention types described in chapter 4 across the entire Airbus UK case study.

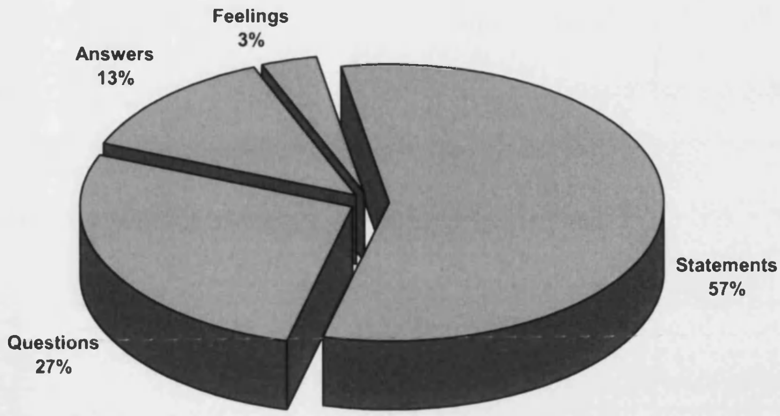

Figure 5.4 *Intervention types transcribed during both AUK design reviews (% interventions)*

In the pie chart (figure 5.4), a critical aspect of spoken discourse is unveiled: questions are not always answered directly and are sometimes hidden in a more global statement. This explains the difference in percentage between the "questions" and "answers" categories. A typical example is given in passage 2 below.

Passage 2: from the Airbus RR transcript (between 00:32:08 and 00:32:52):

Question: *"Well what I'm saying is: is that request already in ABD0100 or do we have to reiterate it?..."*

Statement: *"There's just a commercial element in that though, if ... we reject their maturity plan for whatever reason and it doesn't meet our requirements and they haven't taken that account in their quote they can slack a claim on us and we end up in a pay debt"*

Statement: *"I think it's hidden under my concern /is that/"*

Statement: *"/We don't want/ to pay/"*

Statement: *"/If you're half way down the program, you've dealt with your contracts, recently started to talk to Supplier about hundreds of hours of maturity testing on such a rig and they come back to you and say: yep fine here's the extra bill."*

Statement: *"Get it all in up front"*

This aspect of speech has direct consequences for the use of design rationale tools during meetings. A number of design rationale capture solutions, detailed in chapter 2 (§4.3.1), prescribe an IBIS approach to effectively capture information during design situations. This approach has been extended to meeting situations with dialog mapping tools (see chapter 3, §4.2). The grouped bar charts in figure 5.4 suggest that the IBIS-based techniques would most probably fail to capture a significant amount of crucial information and knowledge; the nature of the "question and answer" communication process is not as explicit and straightforward as one might expect.

The results illustrated in figure 5.5 enable to explore further the "intervention" coding element by using it to characterise the exchange roles deployed for the purposes of the TCS.

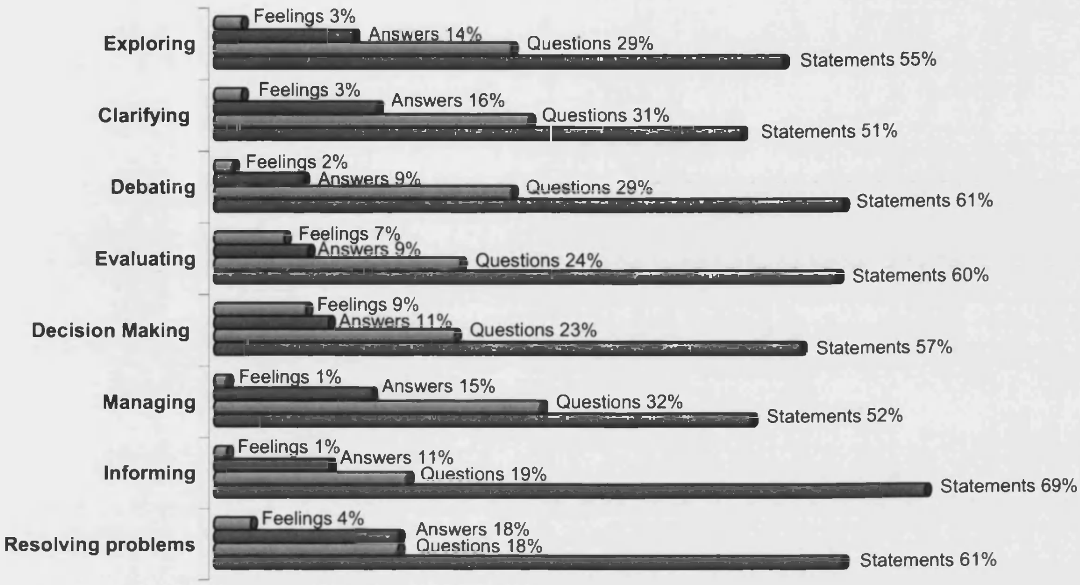

Figure 5.5 *Intervention types per exchange roles observed over both Airbus UK design reviews (% interventions)*

To complement the remarks made previously on the use of an IBIS method to capture design rationale, figure 5.5 suggests that the "resolving problems" exchange role would be the only situation where dialog mapping could be employed. Indeed, "resolving problems" is the only exchange role where direct "question and answer" procedures have been observed. Although the results encompass both meetings, this aspect has been verified individually for the RR and the PDR when the author compiled the results.

Some characteristics outlined in figure 5.5 were widely expected: "informing" is essentially composed of statements, "debating" and "clarifying" have a high number of questions which are not necessarily answered directly. Then, there are a few revealing aspects of the communication structure in meeting discourse: "managing" shows the highest proportion of questions, while "evaluating" and "decision making" have the highest proportion of feelings involved.

In fact, the "managing" exchange role essentially characterises discussions related to the management of the meeting and the project. The design review is indeed the ideal event to bring up questions about the management of the project or the design review activity in itself, as illustrated in passage 3.

Passage 3: from the Airbus RR transcript (between 00:00:46 and 00:01:07):

Question: *"Well the offer is on the table if somebody decides they've had enough and need to move on ... and hmm we're not going to get kicked out at 12 o'clock are we?"*

Answer: *"No, we've got at least until 1 O'clock ..."*

Question: *"So you've provided lunch as well? ... [laughs]"*

Finally, "decision making" and "evaluating" are exchanges which seem to generate more feelings and emotions from the speakers than other communication processes. This is understandable as both these activities are core to the design review and therefore tend to draw the focus and expectations of all the participants, as illustrated in passage 4 below.

Passage 4: from the Airbus UK RR transcript (between 00:09:35 and 00:10:12):

Statement: *"One comment that I made is that there are numbers quoted for the tank with dry bays, we ought to quote it for ... without"*

Question: *"For fuel quantities?"*

Answer: *"Yeah approximate quantities ... otherwise it seems inappropriate to have just one set"*

Statement: *"Or at least identify what the quantity of a dry bay is ... so it's one way or the other"*

Feeling (from several of the participants): *"Yeah ..."*

Statement: *"... So that's an action please then"*

2.2. Communication intent

This section will primarily focus on the analysis of the results from the "exchange role" coding element, used in full by the TCS and simplified in the MCT. The general communication intent of the design review can effectively be described using this coding element. Figure 5.6 illustrates the results across an entire aerospace design project, from RR to CDR, thanks to the data captured from the CAMAQ project case study with the MCT.

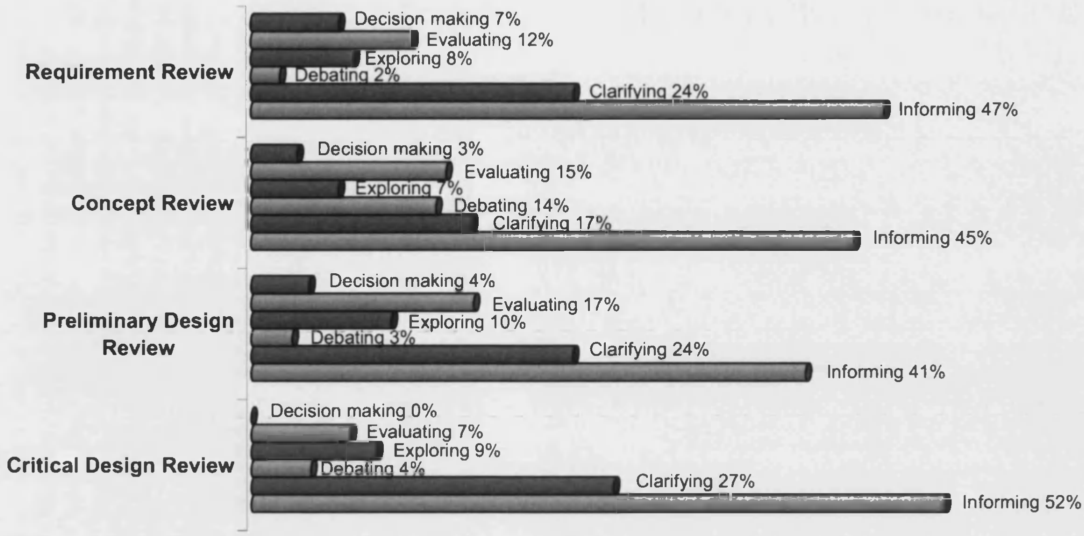

Figure 5.6 *Evolution of the exchange roles across the CAMAQ project design reviews (% conversation time)*

The striking aspect suggested by the graph in figure 5.6 is the importance of "informing" and "clarification" activities. Combined, these exchange roles occupy 60-70% of the conversations and therefore underline the importance of the "sharing information" activity suggested by the design review process model presented in chapter 3. "Evaluating", "exploring", and "decision making" are the key communication activities which can be related to the two other design review activities proposed in the process-oriented model: "evaluate the design" and "manage the design".

It is also interesting to observe the joint evolution of communication and design activities across the life of a design project. A preliminary remark needs to be made on the 0% value for the "decision making" exchange role in the CDR (see figure 5.6): the CDR marks the end of the CAMAQ project and this explains why no decisions are taken at this point. Nevertheless, figure 5.6 shows how a number of decisions were taken early on in the project. Apart from "informing" and "clarifying", the RR shows an important percentage of "exploring" and "evaluating" activities where participants made sense and decided of the design goals and processes. The CR is characterised by high levels of "evaluating" and "debating" communication exchanges. These are directly linked to the various design concepts under review and suggest a collaborative creation and synchronisation of knowledge. The PDR has the highest percentage of "evaluating" exchanges so that the detailed design activities ensure a mature development of the selected concept. A majority of the time spent during the CDR was used to inform the clients of the finalised solution.

The TCS enables a finer analysis of the communication intent within a meeting. Figures 5.7 and 5.8 depict the evolution and the overall results for the "exchange role" coding element for the Airbus UK RR and PDR. The values must not be directly compared to those shown for the CAMAQ project because the Airbus UK design reviews where held at a lower level of the aircraft component structure and involved expert participants; less "informing" is expected in a professional context as many participants have already common design references, especially in the case of standard components design or integration (see chapter 2, §1.2).

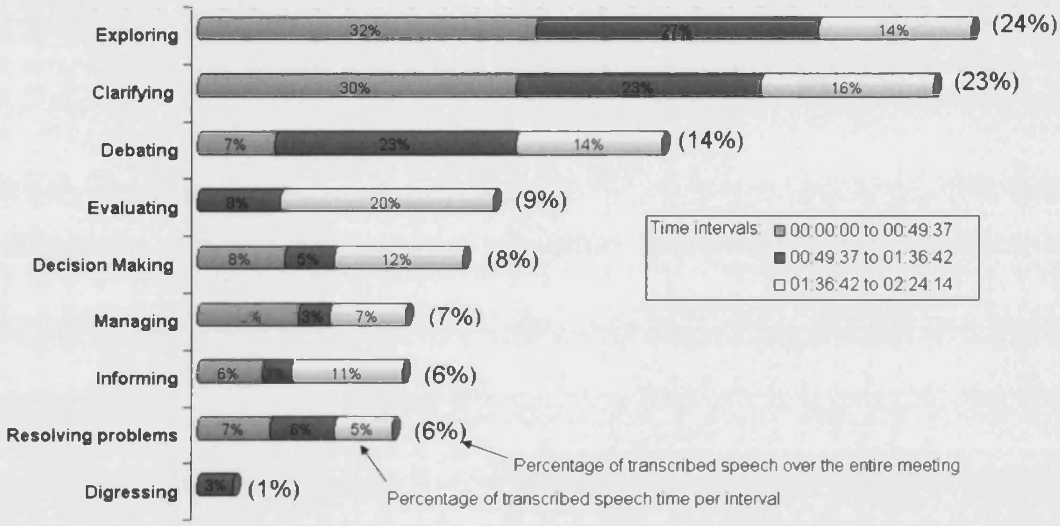

Figure 5.7 *Evolution of the exchange roles during the Airbus UK RR*

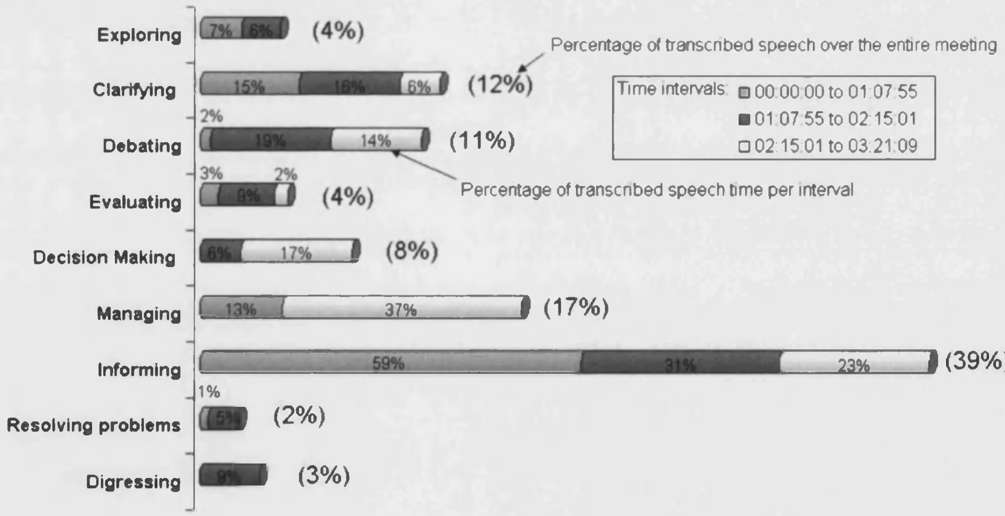

Figure 5.8 *Evolution of the exchange roles during the Airbus UK PDR*

Figure 5.7 clearly outlines the importance of "exploring", "clarifying", and "debating". Indeed, the RR aimed at exploring each requirement in order to make sure that the supplier would meet the expectations of the client (in this case Airbus UK). This meant that the participants had to synchronise and clarify their individual understanding of the expected design, which led to a number of clarifications and debates.

Figure 5.8 again illustrates how the Airbus UK PDR focussed on gathering information, clarifying the supplier's achievements, and updating the management of the project so that the design and manufacturing activities could be carried out according to plan.

Figure 5.7 and 5.8 also show the evolution of each exchange role within the meeting. This was achieved by simply sectioning the transcripts in three intervals of approximately the same time. Although it is difficult to generalise the results obtained with just two design reviews transcribed, table 5.1 outlines the preliminary pattern observations which can be made based on the Airbus UK case study. Only clearly marked trends have been summarised in the table.

***Table 5.1** Summary of the observed occurrences of "exchange roles" within a design review based on the Airbus UK case study*

Exchange Role	Typical observations during design reviews divided in 3 intervals
Exploring	Observed in the first two parts of each meeting
Clarifying	Observed across both meetings, but to a lesser extent in the final part
Debating	Notably more frequent in the middle of the meetings
Evaluating	No real pattern emerged, but present in the middle part of both meetings
Decision making	No real pattern emerged, but more frequent at the end of both meetings
Informing	No real pattern emerged, frequent across the meetings
Managing	Frequent at the start and at the end of the meetings
Resolving problems	No real pattern emerged, present in the middle part of both meetings
Digressing	Occurred in the middle part of both meetings, when less "managing" is felt

From table 5.1, a preliminary model of communication activities can be proposed: the participants start by clarifying and exploring issues before debating, evaluating, and resolving problems. They finally move to decision making while having continuously informed their colleagues about their vision of the design space.

2.3. Observing a specific communication pattern: the decision making process

One of the key design communication interaction scenarios often associated to a design review is the decision making process. Even if the previous sections and the design review process-oriented model presented in chapter 3 clearly suggest that this type of meeting is much more than an event for decision making, it is nonetheless an important aspect to consider and analyse.

In order to observe decision making patterns in design reviews, the data from the Airbus UK case study was used with the 9 exchange roles categories coded through the TCS. Table 5.2 summarises the number of occurrences for each exchange role observed prior to a "decision making" exchange. In the two design reviews analysed, a total of 23 "decision making" exchanges were coded. For each one of these occurrences, the two exchanges prior to "decision making" were taken into account, as shown in table 5.2.

***Table 5.2** Summary of the occurrence of exchange roles observed prior to decision making across both Airbus UK design reviews*

Exchange role	**1st position prior to decision making (number of occurrences)**	**2nd position prior to decision making (number of occurrences)**
Exploring	**6**	1
Clarifying	2	**4**
Evaluating	**6**	3
Debating	2	1
Decision making	2	**4**
Informing	2	**4**
Managing	2	2
Resolving problems	0	3
Digressing	1	0
Not coded[1]	0	1

[1] *Note: "not coded" means that the exchange was not transcribed or corresponded to a pause in the conversation.*

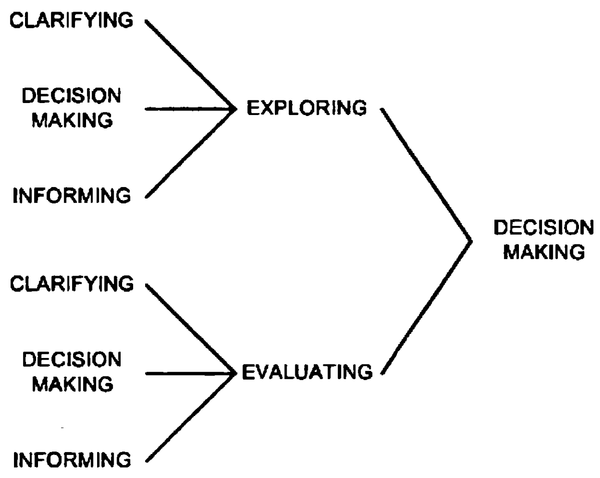

***Figure 5.9** The essential decision making patterns observed during the Airbus UK design reviews*

Critical decision making patterns were then outlined by selecting the exchange roles with the highest number of occurrences. Figure 5.9 illustrates the 6 essential patterns based on the results of the Airbus UK case study. These patterns fall into the typical "sequence" procedure category prescribed by Badke-Schaub and Gehrlicher (2003), mentioned in chapter 2 (§4.3.2). These "sequence" procedures observed during the DTM case studies reflect a rational course of decision making where participants have no conflicts of interest (Badke-Schaub and Gehrlicher 2003). To complete the illustration of certain decision making paths highlighted in the global pattern in figure 5.9, a couple of examples taken from the Airbus UK design reviews transcripts have been reproduced below in passages 5 and 6.

Passage 5: from the Airbus UK RR transcript (between 02:06:50 and 02:08:41):

Decision making:

"Is there a similar risk regarding ACTs? If we haven't tested on ACTs can we certify this on ACT airplane?"

"We can't have a flight test aircraft available to meet our requirements ... That's the risk"

Evaluating:

"... And finally, but this might be replicated elsewhere, the delay of the issue of the part A which would probably include the delay between phase 1 and phase 2. But I still put it down as a separate risk"

"When do you think you can resolve that one?"

"I was hoping by the end of this week but it seems very unlikely, I've got to get hold of Phil and PS together, to sign it"

"And to get their comments"

"Yeah I've had their comments and implemented their comments but PS still has a couple to go or he wants some more assurance so it's going for the end of this week but it's more when I can get hold of them ... and that was that."

Decision making:

"You've got 2 new risks to put on our sheet"

"For the flight test aircraft, it may not be available so ... to meet our requirements... and hmmm the issue with the ..."

"There's the dry bay definition"

"John's already got an action"

"... Smashing"

Passage 6: from the Airbus UK RR transcript (between 00:25:06 and 00:27:55):

Clarifying:

"In that case, make sure I'm clear of what you're telling me here, we previously developed the software to level A, new software should be developed not to A ... my terminology here, sorry DO-178 issue A and we now need to go to future software, we are supposed to be using DO-178B, where we are modifying the software, the question is: do you use A or B? From the project office point of view we have a definition that says that if it's a ... only a modification to an existing software then it's open to debate, and I think what you're saying is we are moving towards saying that the modified software the part of the software which is changing should be changed according to B, but we don't have to validate the whole software to B?"

"No"

"That would be a very good solution"

"Is there some regression testing that covers the ..."

"When you come up into the integration level, then of course you have to consider B instead of A, so at the module level, at the lower level then it's only change components against B and when you go to the integration you're talking B instead of A"

Exploring:

"What's that going to imply for the program?"

"There are a couple of extra activities or a couple of extra things that they need to account, most of the suppliers that we have spoken to today have already taken B into account as far as their development methodology is concerned so it's not a problem list of suppliers as far as this one is concerned this is Supplier?"

"Supplier, yes"

"When I did a part 6 on Supplier, they moved their procedures to standard B, so in theory I don't think there's a problem but obviously when TT does his first review with them that will obviously be taken into account"

"And these have been applied to Supplier2?"

"Once again we know Supplier2 have gone to B anyway but there are procedures"

"Obviously B gives a better software"

Decision making:

"Supplier are aware of our position?"

"They are"

"Well ... we've said that from day one that we wanted B anyway"

"So all the plans should have already been taken into account"

"I think, subject to our discussion tomorrow evening, tomorrow evening meeting, I think we need to assume that this section will have to be updated"

"Sure"

"Ok, I've taken that as an action"

Of course, the proposed decision making patterns are limited to the observed design reviews, but the analytical approach described in this paragraph provides an interesting perspective to complement the construction of GDSS software (see chapter 3 §4.1.3), for example, based on empirical meeting data.

3. DESIGN REVIEWS FROM AN INFORMATION PROCESS PERSPECTIVE

The meeting models detailed in chapter 3 (§2.1 and §2.2), especially the process-oriented perspective of design reviews, have outlined the expected conceptual information processes which might occur during the event. This section will now supplement these theoretical models through the characterisation of the information processes observed during the Airbus UK and CAMAQ project case studies, using respectively the TCS and the MCT. The results provided by both these analytical tools have been grouped according to three complementary perspectives: the structure, the content, and the type of information exchanged.

3.1. Structure of the information exchanged

Section 2.1 has presented the main aspects in terms of communication structure based on the observed case studies; this section will now focus on the structure of the information elements exchanged during both Airbus UK design reviews. The "topic origin" coding element in the TCS provides a good insight into the spoken information structure of a meeting by assessing if the topic of conversation under observation was predetermined, i.e. proposed in the meeting agenda, derived from the agenda, or completely unexpected.

Figures 5.10 and 5.11 illustrate the overall results of the "topic origin" coding elements for respectively the Airbus UK RR and the Airbus UK PDR. Both pie charts testify to the degree of formality of design reviews, and these figures, combined with the values for the "digression" exchange role presented in §2.2, are clear indications of the high level of structure which governs the information processes observed during this type of meeting.

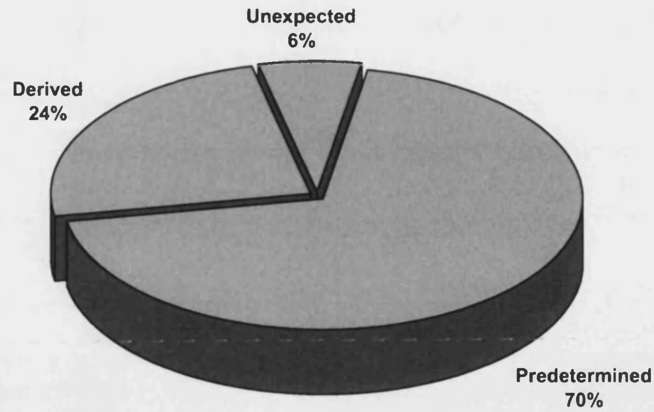

Figure 5.10 *Origin of the topics discussed during the Airbus RR (% conversation time)*

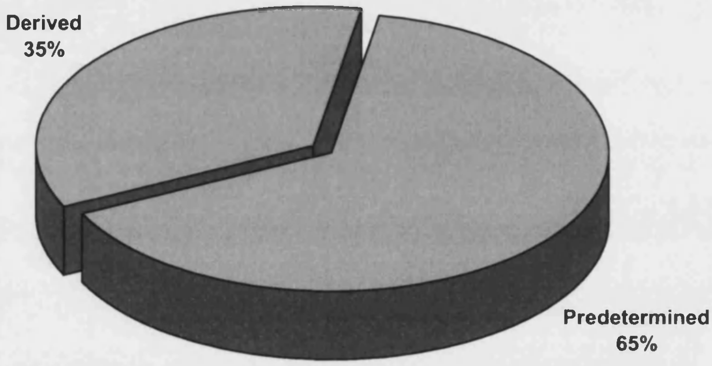

Figure 5.11 *Origin of the topics discussed during the Airbus PDR (% conversation time)*

In the case of the RR, figure 5.10 shows that 6% of the transcribed topics were unexpected. It can be easily understood if the RR's explorative role, described in §2.2, is considered. Indeed, this meeting was an ideal opportunity for the participants to discuss unexpected topics, unlike the informative nature of the PDR.

Nevertheless, a much higher "unexpected topic" value in an explorative situation could have been anticipated. One of the plausible explanations for this low figure (6%) could come from the design artefacts under review in the RR. The participants discussed the contents of technical and procedural documents – the equipment specification, the certification plan, the risk register, and the project management plan – and were also guided in their exploration by other formal documents: the statement of work and the milestone plan. It seems clear from this example and from the general use of artefacts outlined in chapter 3 that these documents played an important role in the structure of the exchanged information during design meetings. Passage 7, taken from the RR transcript, illustrates how the explorative discussions were often guided by specific artefacts, in this case a number of procedural documents.

Passage 7: from the Airbus UK RR transcript (between 01:10:25 and 01:12:10):

"Ok you've just got a summary in there and we'll go over the detail and that can be reflected in the summary in due course but one thing that sprang to mind fairly early on when I started looking at this document was that we'd never picked up on the EP 1013 or GRESS as it's more commonly known. I wondered if you guys had any opinion on the applicability of the GRESS, that's General Requirements for Equipment and System Suppliers because I've seen that referred to more and more regularly in engineering documents. Are you planning on using that or any parts of it?"

"I hadn't planned on it no!"

"If you look at this in the AP100 and 200, we say we'd like to apply the spirit of those documents if not actually require those documents and I wonder if the GRESS is not applicable in a similar manner, because from your understanding of all the benefits that are accrued form using the GRESS you are wondering whether or not use features from the GRESS to enhance this particular project."

"I think we said that ABD 100 is in effect applicable or as much as we can make it so but ABD 200 isn't. Now if we stick to that then I guess the GRESS also doesn't become applicable because that's where the link would be."

"OK"

"GRESS has already been agreed at Supplier ..."

"Oh..."

"Yes, as a general document they have agreed to use it. All equipment is being used on it"

3.2. Categorisations of the information content

One of the major issues in the development of the TCS and MCT described in chapter 4 was the categorisation of the information content of design reviews. For the MCT, two distinct approaches were taken. In a first instance, each entry in the MCT was codified (post-meeting) using a basic categorisation of the topics with 3 generic categories: design, manufacture, and management. The results of this simple classification scheme applied to the CAMAQ project design reviews are shown in figure 5.12.

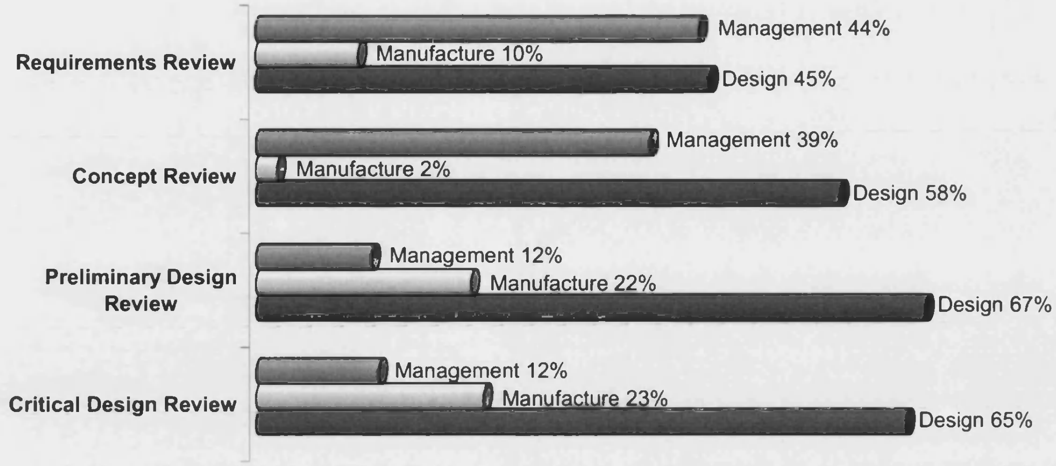

Figure 5.12 *Evolution of the generic topics of discussion across the CAMAQ project design reviews (% conversation time)*

The evolution shown in figure 5.12 is a perfect illustration of the integration of design and manufacturing according to Concurrent Engineering practices. The focus on design peaks around the PDR, while project management issues are brought early on in the project. The most interesting part is the evolution of topics linked to manufacturing issues. They are brought up during the RR, but then the CR is completely focussed on the design; this illustrates how manufacturing constraints are integrated as soon as possible in a design project so that the concepts generated for the CR are within a specific design space limited by the manufacturing capabilities of the company.

The MCT provided another means of tracking discussion topics through the categorisation of the participants. This approach did not require post-meeting processing and used the 6 participant categories available in the MCT. The results are shown in figure 5.13. In fact, this analysis was initially based on the assumption that speakers participate in discussions according to their domain of competence. Of course, this is not always true, but when comparing figure 5.12 and figure 5.13 strong similarities can be observed between the two categorisation approaches. This strongly helps to validate the point in the hypothesis that participants act only within their domain of knowledge during a design review.

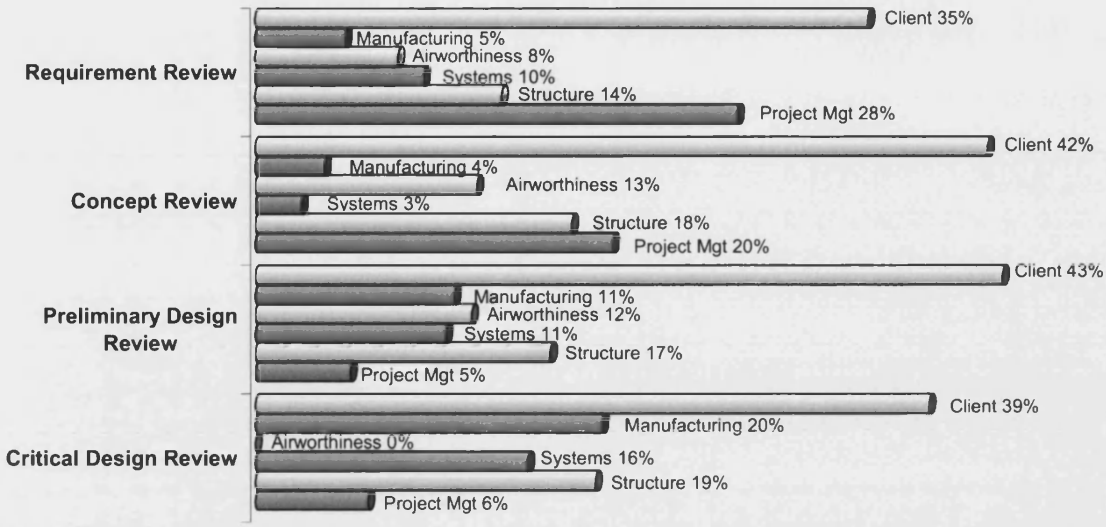

Figure 5.13 *Evolution of the participant involvement per domain of competence in the CAMAQ project case study (% conversation time)*

A couple of qualifying remarks need to be made concerning figure 5.13. As mentioned previously in §2.2, the CDR was not completely representative of similar meetings in the industry for only two reasons:

- The students did not have any actions to carry out after this meeting.
- The certification issues had been dealt with separately, prior to the CDR.

Nevertheless, figure 5.13 successfully illustrates and further reinforces the Concurrent Engineering practices outlined in figure 5.12.

In the case of the Airbus UK design reviews, the analysis of the information content, effectively managed with the TCS, required a number of iterations before an adequate solution was reached. Chapter 4 has outlined the main transformations to which the TCS was subject for the "topic" coding element. The final TCS adopted a generic topic categorisation using the typical domains of competence found at Airbus. The difference with the MCT is that the domains of competence were not tracked through participant involvement, but with the clustering of the interventions into conversation topics.

Figure 5.14 and 5.15 illustrate respectively the results for the Airbus UK RR and PDR using the TCS method for topic tracking. As stated previously, because the Airbus UK design reviews were part of the design process at a component level, some aspects are not directly comparable to the CAMAQ project design review, which was a design project carried out at a module level of the aircraft. Still some characteristics seem to persist throughout these case studies: there is a significant decrease of the project management involvement between RR and PDR, while design topics increase. Also, it is important to note the constant implication of certification and testing issues, which guide and constrain the design space in most, if not all, aerospace design projects.

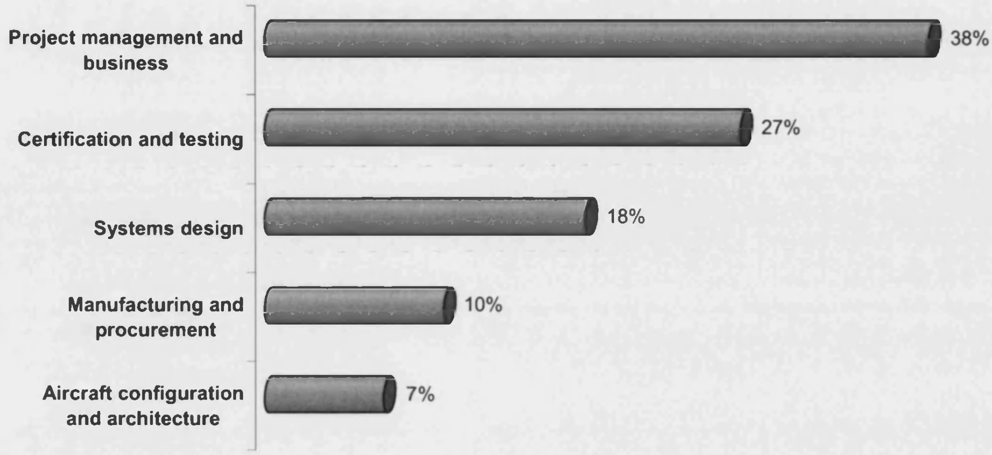

Figure 5.14 *Distribution of the conversation topics according to the domains of competence involved during the Airbus UK RR (% conversation time)*

For the RR, figure 5.14 shows the importance of "project management" and "certification and testing" issues. These domains of competence were actually closely related; the participants were gathered to discuss how to present the design requirements so that the supplier would effectively produce mature parts in order to test and certify the aircraft fitted with these new parts using the Airbus testing facilities. Passage 8 taken from the RR transcript illustrates this concern.

Passage 8: from the Airbus UK RR transcript (between 01:48:03 and 01:44:44):

"When you do this early it makes you think up front what you want to do ... so rig testing, flight testing, different types of testing pre selected fuel, design clearances, FQI calibration consult GTRs, possible ground test ... yeah that's great, I mean at the moment putting what you think we need to do, we can always take things out ...I'd rather see things in here and take them out later than trying to add them in. It's a lot easier to cancel an A/C than to arrange it"

""A Verification Matrix providing full traceability of results for each verification" so this matrix against each requirement there will be ... how are we to respond to ... and this matrix will also cover those elements of the spec that didn't change, will we still be checking that the unchanged parts work"

"In general yeah, generally"

"So the test coverage will be complete not just for the parts that have changed"

"So at this point it also sprang to mind again, at this time we also need to define what we need in terms of the supplier for maturity testing whether that's a software, equipment or system level, what sort of operational test will be required, ground flight, how many hours ... in fact that's what we've been doing with SupplierX, SupplierX can now come to us and say: "we've been testing this new kind of computer for 1000 hours."

In figure 5.15, the bar chart illustrates the surprisingly low involvement of "manufacturing and procurement" in the conversations. In this case, the meeting was held to review the design change of a pin and impeller in a trim tank pump assembly. The main concern for the review team was whether the new pin and impeller were effectively improvements of the old versions and would prevent failure. The Airbus team was responsible for the design approval, which was conditional to the launch into production of the new parts by the supplier. This meant that the review team was not really interested in the manufacturing issues but rather in the maturity of the design. On the other hand, the supplier was continuously building a case in order to launch the production of the new parts as quickly as possible. This aspect of the information content of the meeting is well illustrated by the passage 9 taken from the Airbus UK PDR transcript.

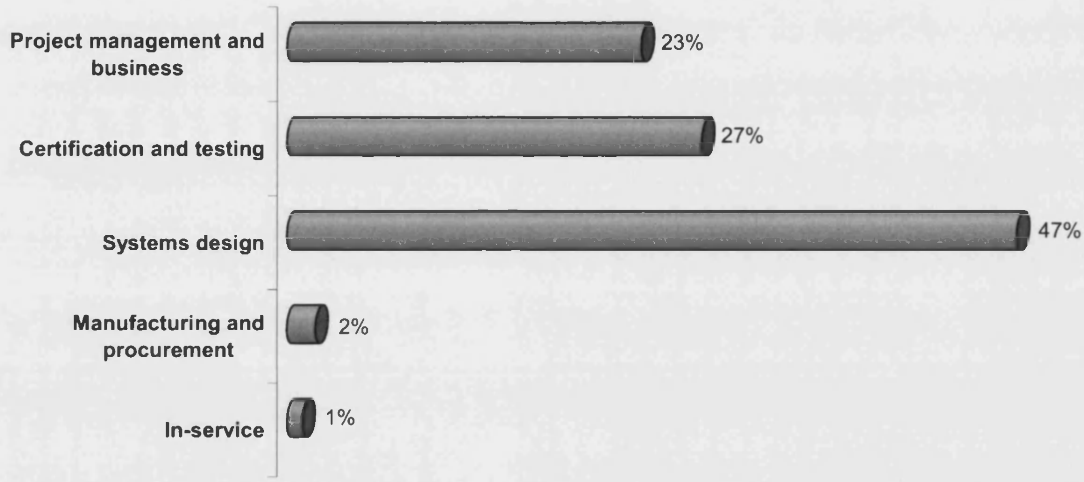

Figure 5.15 *Distribution of the conversation topics according to the domain of competence involved during the Airbus UK PDR (% conversation time)*

Passage 9: from the Airbus UK PDR transcript (between 01:51:35 and 01:53:52):

Airbus: *"I think in particular as well, JL touched it earlier, item number 13 on your schedule there: receiving AUK approval for December, I guess the question is: what level of approval are we looking at there? ... As JL said we would expect to be seeing some sort of testing that's done maybe ahead of a CDR, some formal testing post CDR and at some point after that then we'll give you effectively the instruction to go ahead and say yeah we are happy with those changes, testing approved and results looks good and then you can kick off production from there ... now obviously that 5th December looks rather tight to do all that / That's right /"*

Supplier: *"/ Well that's before we /"*

Airbus: *"/What you need / we probably wouldn't get an EDES signed"*

Airbus: *"No I don't think so"*

Airbus: *"The other problem would be your DDP ..."*

Supplier: *"I think we need the formal approval before we can ship the units (...)"*

Airbus: *"Yeah that's right, that's one way of looking at the issue, is to say this is the program to build units at risk ... because it doesn't quite tie with maybe what we are expecting in terms of the next months in terms of CDR expectations etc.../ I think we need more detail schedule /"*

Airbus: *"/ I think I'd like to see/ something as in what you think you can do and what testing you can do and we need to discuss / round /"*

Airbus: *"/ Yeah I think that's /probably best (...)"*

3.3. Information types

Both the TCS and MCT propose useful approaches to categorise the information contents of a meeting based on the involvement of the participants or the domain of competence related to the topic of discussion. From a product life-cycle perspective, it is also interesting to outline typical profiles of engineering and business activities in terms of Product, Process, Resources, and External factors (PPRE) information types so that the information captured can be efficiently manipulated using the appropriate information modelling techniques, as described in chapter 2 (§3.3).

This section will therefore propose an analysis of the types of information encountered during design reviews based on three specific studies: the PPRE information types tracked by the TCS, the product versus process information trends observed across the CAMAQ project case study, and the type of artefacts encountered during the Airbus UK case study.

3.3.1. Analysis of information types based on the TCS

In the specific context of a design review, the TCS includes an "information type" coding element which has generated interesting profiles for PPRE information exchanges in the case of both the Airbus UK design reviews (see chapter 2, §3.3). Figure 5.16 and 5.18 illustrate the overall results for the entire meetings using pie charts, while 5.17 and 5.19 detail the distribution of the PPRE information types for each exchange role with subdivided 100% bar charts.

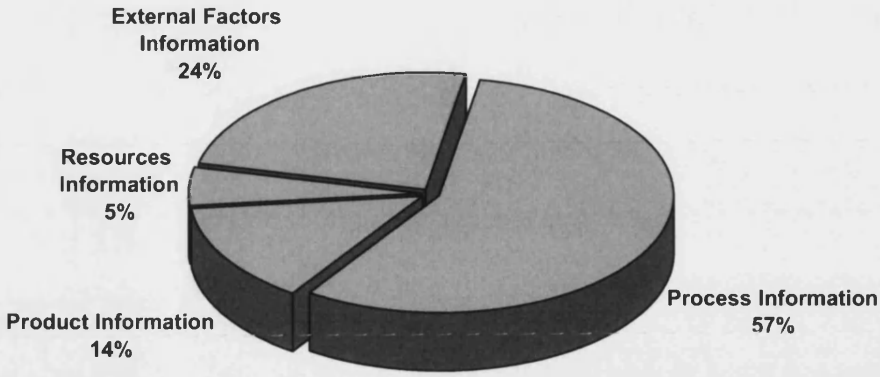

Figure 5.16 *Distribution of PPRE information types for the Airbus UK RR (% conversation time)*

In the case of the Airbus UK RR, figure 5.16 shows how most of the discussions were directed towards the design process rather than the product itself. This distribution is a direct consequence of the fact that the actual design of the product was to be achieved by the supplier and therefore the Airbus project team was responsible for ensuring that the appropriate verification and validation processes would be in place to meet product maturity requirements. The "external factors" category was also important as this type of information, by definition, relates to the constraints imposed on the product and its design processes. During the RR, the participants were effectively only concerned about correctly wording the design requirements in order to constrain the supplier's design space and avoid any legal debates in case of unfulfilled requirements.

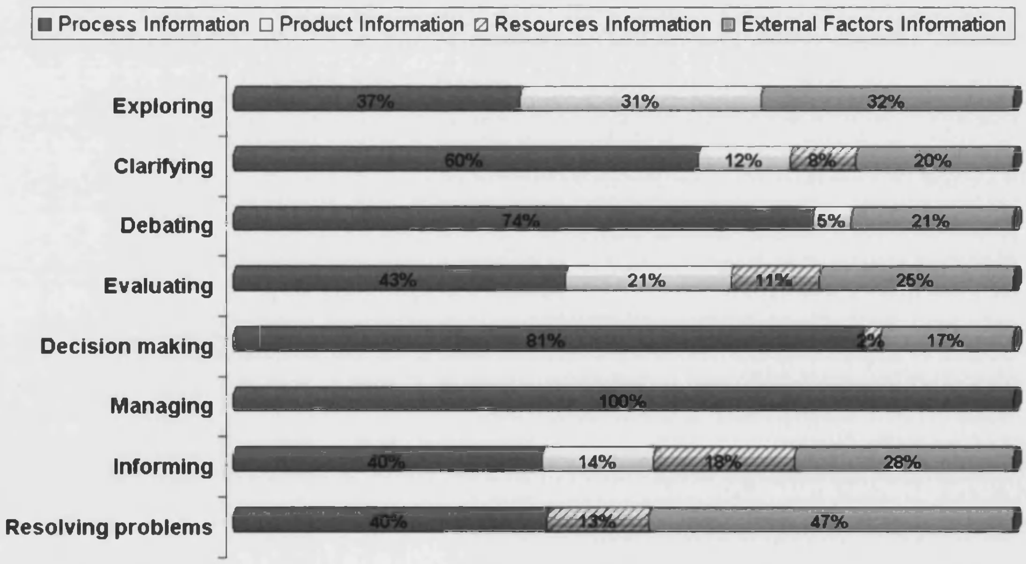

Figure 5.17 *Distribution of PPRE information types per exchange role for the Airbus UK RR (% conversation time)*

Figure 5.17 refines the analysis of the PPRE information types observed during the RR by associating them to the 8 main exchange roles tracked by the TCS (the "digressing" category was not judged relevant for this specific study). From the results, it is possible to label each information type with its underlying communication intent and its role in the process-oriented model of a design review described in chapter 3, §2.2.

- *Process information* was at the centre of "managing", "decision making", "debating", "clarifying", and "evaluating" communication exchanges. This type of information was basically core to the entire design review and at the top of the participant's preoccupations. Process information was used in all three design review activities: "share information about the design", "evaluate the design", and "manage the design".
- *External factors information* generated "resolving problems", "exploring", "informing", and "evaluating" discussions. The design constraints contained in this information type needed to be fully established and agreed upon before the documents could be passed on to the supplier. These results highlight the involvement of this information type in "share information about the design" and "evaluate the design" activities.
- *Product information* was essentially present during conversations dealing with "exploring", "evaluating", and "informing". Indeed, most of the information exchanged between participants about the product was directed towards understanding the product requirements to be passed on to the supplier. This shows how this type of information was mainly used during a "share information about the design" activity.
- *Resources information* was present during "informing", "resolving problems", and "evaluating" conversations. These dominant exchange roles suggest that this type of information was mostly used during an "evaluate the design" activity.

In the case of the airbus UK PDR, figure 5.18 illustrates the distribution of 3 information types across the meeting: "product information", "process information", and "external factors information". "Resources information" was not discussed during this design review.

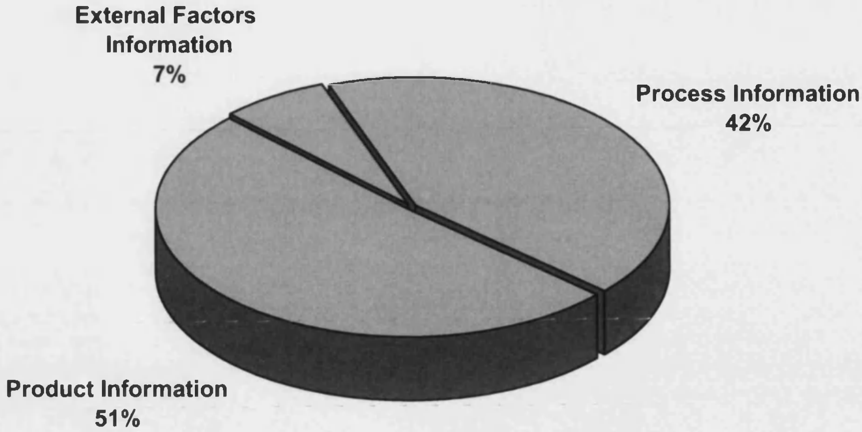

Figure 5.18 *Distribution of PPRE information types for the Airbus UK Preliminary Design Review (% conversation time)*

During the PDR, the focus of the conversations was balanced between process and product information with a few discussions about the testing constraints imposed by Airbus UK on the design proposed by the supplier (external factors).

The results presented in figure 5.19 enable a finer analysis of the use of the PPRE information types during the PDR.

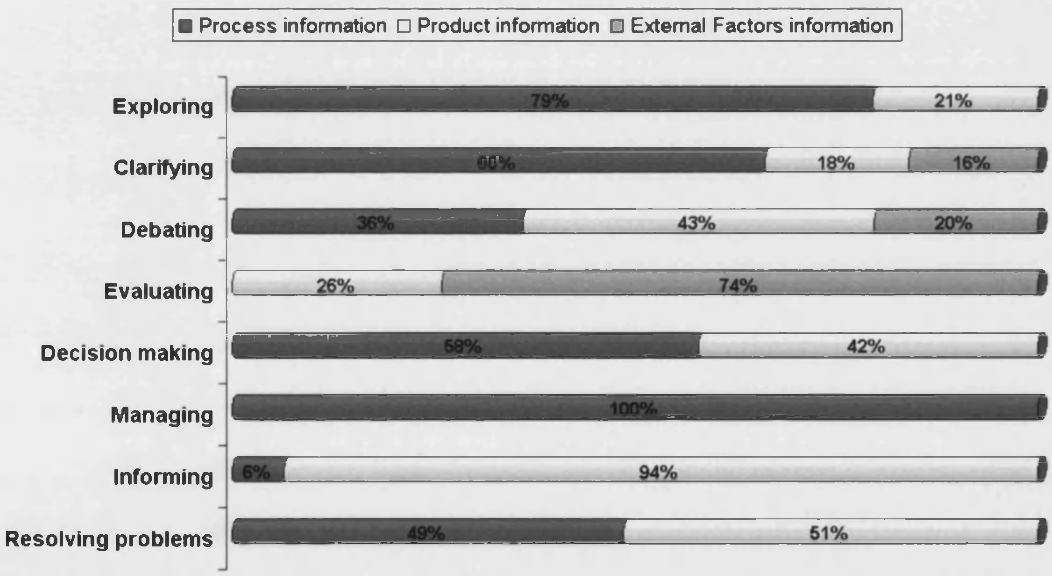

Figure 5.19 *Distribution of PPRE information types per exchange role for the Airbus UK PDR (% conversation time)*

In the same way as for the RR results, it is possible to label each information type that has been tracked in the PDR with its underlying communication intent.

- *Process information* is present for all the exchange roles, except "evaluating". In this case, conversations about process issues were confined to "share information about the design" and "manage the design activities", although they must have had an impact on the evaluation process. It is also important to underline the fact that these discussions about process information were often initiated by the Airbus UK team in order to probe the design rationale followed by the supplier.

- *Product information* was generally the focus of the discussions initiated by the supplier. The general aim of the design review was effectively to evaluate the design proposed by the supplier. The supplier therefore concentrated on providing extensive information about the adopted solution. "Informing", "resolving problems", "debating", and "decision making" were the main exchange roles involved when considering product information. "Share information about the design" and "evaluate the design" were therefore the essential meeting activities related to product information.
- *External factors information* was at the centre of the "evaluate the design" activity. "Evaluating", "debating", and "clarifying" were the only exchange roles related to this type of information. The values, combined with the observations made for the two other information types, illustrate how the review of the design and its process enabled the Airbus review team to impose new constraints on the supplier so that the product would meet their expectations. Overall, external factors information was the main focus of the "evaluate the design" activity.

3.3.2. Product versus process information based on the CAMAQ project case study

The MCT offers a simplified approach to track the information types generated between participants in a design review. As mentioned in chapter 2, engineering information and knowledge models have essentially focussed on product versus process information. For this reason, the results of the MCT shown in figure 5.20 outline the evolution of product versus process information across the CAMAQ project design reviews.

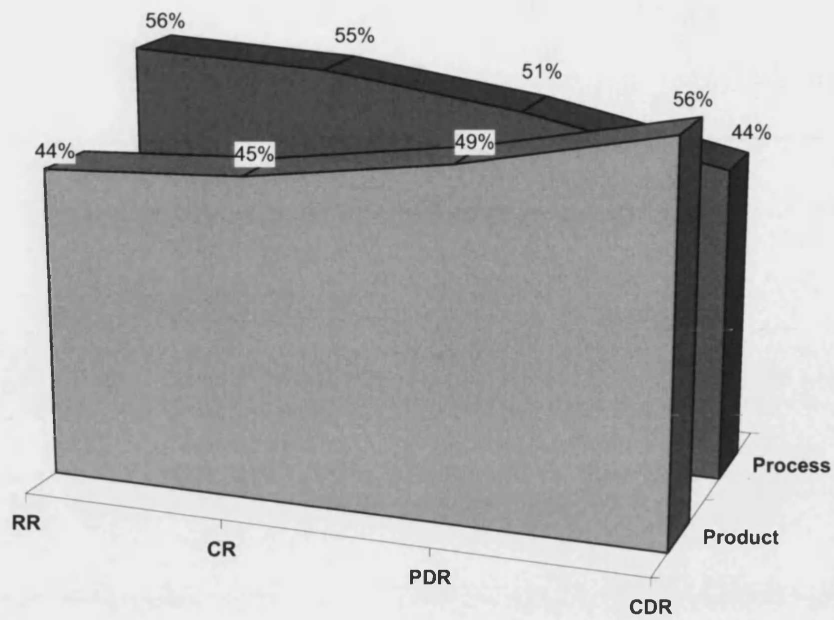

Figure 5.20 *Evolution of product vs. process information across the CAMAQ project design reviews (% of conversation time)*

The results in figure 5.20 are a unique illustration of the shift in balance between process and product information that occurs during the evolution of a design project. Indeed, a number of the authors mentioned in chapter 2 (§4.3.1) suggested this trend, but often without any hard evidence. The CAMAQ project data confirms these initial impressions and the model proposed in figure 5.21 suggests the influence of 2 essential variables, α and X, in the interaction between the process information and the product information curves.

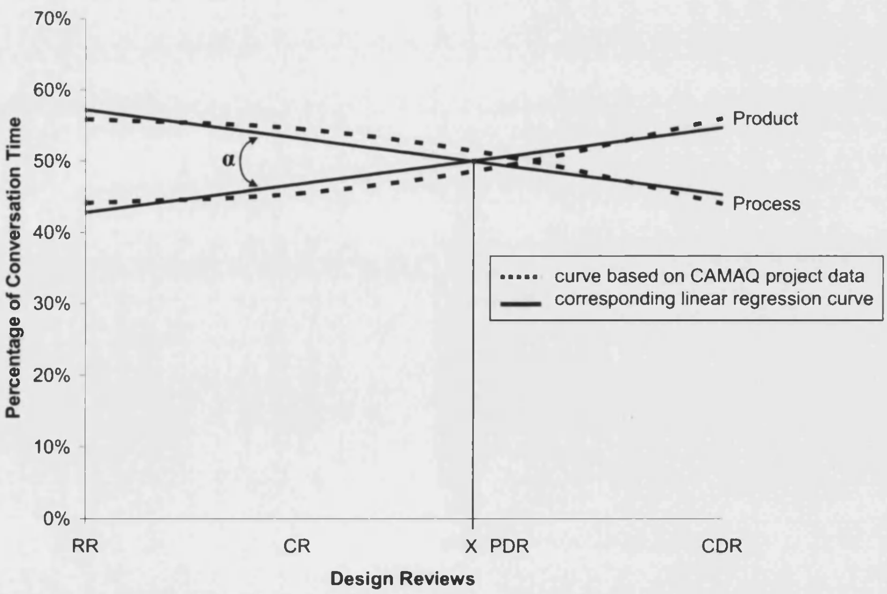

Figure 5.21 *Influence of the essential product vs. process information variables*

The values provided by CAMAQ project data can be seen as a specific situation, but when combined with the Airbus UK results presented in §3.3.1 it is possible to outline a number of interesting hypotheses.

- Process and product information are shared in large amounts across the life of a design project. This implies that techniques and systems aiming at capturing design rationale should propose a hybrid (product/process) approach in order to fulfil their goals.
- In the observed DTM case studies, the equilibrium point (X) between product and process information was typically reached around PDR as shown in figure 5.2.
- The position of the equilibrium point (X) and the angle (α) between the 2 corresponding linear regression curves vary most probably according to a number of external factors related to the nature of the design project. These would definitely include:
    - The nature of the design activities (creative, adaptive, or routine).
    - The position of the designed component in the product structure hierarchy.

3.3.3. Artefact types used during the Airbus UK case study

For both Airbus UK design reviews, the TCS tracked the artefacts used by the participants to support their communication activities. The simple count of their occurrence in each meeting complements the study of the type of information used during design reviews and also supports the communication intent analysis presented in §2.2. Table 5.3 summarises the results for both Airbus UK design reviews.

***Table 5.3** Summary of the occurrences of artefacts per type during the Airbus UK design reviews*

Artefact type	Number of occurrences in the RR	Number of occurrences in the PDR
Office	0	0
Drawing	0	5
Activity management	7	4
Information management	0	0
Calculation	1	10
Communication	0	5
Component	0	4
Testing	0	3

In the case of the Airbus UK RR, a number of documents guided the communications between the participants: the equipment specification, the certification plan, the project management plan, the risk register, the statement of work, and the milestone plan. Most of them were "activity management" type artefacts (see chapter 3, §3.2). This supports the findings outlined previously: the RR focused mainly on the design process and the design constraints imposed on the supplier embodied in these documents. The various documents have undoubtedly an important role in the observed communication process of the meeting: most of the exchange roles were directed towards the content of these procedural artefacts.

For the Airbus UK PDR, the range of artefacts used seems more varied, although only presentation slides and components were available during the meeting. Nevertheless, presentation slides are a generic artefact type ("communication") and were therefore detailed by the author. Each slide was marked according to a specialised artefact type category (chapter 3, §3.2). With a majority of "drawing" and "calculating" artefacts, the results shown in table 5.3 confirm the importance of information discussed about the product, previously suggested in figure 5.18. It is also essential to note that most of the artefacts used during the design reviews were owned by the supplier; this confirms the supplier's intent of focussing the discussions around the design rather than the validation process (see §3.2), and partly explains the values for "informing" in figure 5.19.

Artefacts presented during a design meeting clearly structure and focus to a certain point both the communication intent and the type of information exchanged between the participants.

4. MEASURES OF KNOWLEDGE LOSS FROM DESIGN REVIEWS

Chapter 4 detailed and illustrated the Information Mapping Technique (IMT) developed for the assessment of the loss or modification of specific knowledge objects in the minutes of design reviews. This section will interpret the findings from the monitored Airbus UK RR to highlight the implications in terms of knowledge loss. The complete data generated for this study is presented in appendix F. A measurement based on a simple count of the number of words will first outline the general feel for the knowledge lost in the Airbus UK case study meeting records.

4.1. General trends

From the transcript and the minutes of the Airbus UK design reviews, a quick comparative study was made based on the number of words encountered in each one of the documents. The results have been summarised in table 5.4. Three criteria were used according to the following definitions:

- The "raw number of words" (ref (1) in table 5.4) is the number of words found in the transcript.
- The "useful number of words" (ref (2) in table 5.4) is the number of words that should typically be found in the minutes. This evaluation is based on the TCS where the interventions made by the participants were grouped according to the exchange role. Some of the exchange role categories will typically carry information which has no real *raison d'être* in the minutes. The author judged that the number of words contained in "clarifying", "digressing", "debating" and "managing" could be subtracted to the total tally in order to get a more meaningful approximation of the "useful number of words" in the transcript.
- The "minuted number of words" (ref (3) in table 5.4) is the number of words referring to the content of the meeting found in the minutes.

Table 5.4 Word counts for the Airbus UK design reviews

		Requirement Review	Preliminary Design Review
Criteria	(1) Raw N° words	17101	7000
	(2) Useful N° words	9330	3850
	(3) Minuted N° words	2224	1300
Ratios	Ratio 1: (3)/(2)	0.23	0.43
	Ratio 2: (3)/(1)	0.13	0.24
	Ratio 3: (2)/(1)	0.55	0.57

Before analysing the results shown in table 5.4, it is important to discuss the apparent difference in size of the two monitored reviews. Effectively, both meetings lasted for over two hours, but in the case of the PDR, the meeting was dominated by a presentation involving the supplier contracted to produce the design. It was part of the research rationale that transcribing the presentation supported by a PowerPoint slideshow was of no great value since this portion of the meeting could be described as a monologue. Nevertheless the various interventions (questions, clarification points etc.) made by the participants during the presentation were transcribed and the PDR minutes summarised the event by inserting the slides in the document. Therefore, the word count for the minutes did not include the words which were part of the PowerPoint document.

In table 5.4, ratio 2 suggests that the secretary of the meeting, in both cases engineers working on the project, tends to reduce the discourse down to around 15-25% of the original number of words spoken. Now, if the "useful number of words" figures are considered, around 50-60% of the conversations would be worth capturing (ratio 3). Finally, ratio 1 shows that the ability to capture the "useful number of words" in the minutes of these reviews varies significantly according to the secretary.

Of course, it is difficult to conclude from this intuitive evaluation based on a word count. The limitations are obvious: for one, the figures are only available for two meetings and more importantly, the count of the number of words is a purely quantitative approach which does not say much about the content and ultimately the value of the information being compared. The use of the IMT will propose a more robust analysis of the actual knowledge lost when using traditional minute taking techniques.

4.2. The IMT results for the Airbus UK Requirement Review

The minutes of the Airbus UK Requirements Review were fully mapped according to the methodology detailed in chapter 4. The minutes accounted for 8 main topics which were at the forefront of the conversations. For the purpose of this comparative study, only the critical topics were analysed. The complete information maps are available in appendix F.

4.2.1. Examples of key knowledge elements tracked in the transcript

The IMT was used only on certain topics of the Airbus UK RR transcript, but in its application it highlighted a number of knowledge elements – decisions, rationale, lessons learnt, and actions – that were not possible to track using the TCS. An example for each one of them is given in passages 10, 11, 12, and 13 below, with the highlighted portion of text representing the information considered as the explicit expression of the knowledge element under consideration.

Passage 10: decisions in a passage from the Airbus UK RR transcript (between 01:23:44 and 01:24:30):

"Next item: responsibilities for validation of FQIC requirements lie with the FQIC vendor. I think that falls quite short of the mark to be honest because we are responsible for validating it in our requirements and they are responsible for validating in their next level of requirements. I think you might want to expand that a bit. Particularly this is another opportunity where I would need to see a definition of what we require them to do. In this management plan I would like us to be saying what sort of validation we are going to request the supplier to do."

Passage 11: rationale in a passage from the Airbus UK RR transcript (between 01:23:44 and 01:24:30):

"Next item: responsibilities for validation of FQIC requirements lie with the FQIC vendor. I think that falls quite short of the mark to be honest because we are responsible for validating it in our requirements and they are responsible for validating in their next level of requirements. I think you might want to expand that a bit. Particularly this is another opportunity where I would need to see a definition of what we require them to do. In this management plan I would like us to be saying what sort of validation we are going to request the supplier to do."

Passage 12: action in a passage from the Airbus UK RR transcript (between 00:27:37 and 00:27:55):

"I think, subject to our discussion tomorrow evening, tomorrow evening meeting, I think we need to assume that this section will have to be updated"

"Sure"

"Ok, I've taken that as an action"

Passage 13: lesson learnt in a passage from the Airbus UK RR transcript (between 00:20:29 and 00:21:08):

"What I'm thinking is lessons learnt, we've had problems with supplier's equipment of late and it comes to pass that the amount of verification that they've done was inadequate to identify that the equipment actually had problems and the opportunity should be taken now to formally identify it to the supplier that we want a more robust V and V activity. How robust, how would you define that, I don't know. I think we should be requiring them to do more than what they've done in the past"

"Are you thinking software, hardware ...?"

"Yes"

"Integration? ..."

"I'm not thinking of any specific element, I'm thinking across the board to be honest"

4.2.2. Characterising the transformation and loss of information with the IMT

The information maps generated by the IMT offer a visual representation of the information contained in a document; comparing the transcript of a meeting and its formal record embodied in the minutes using these maps provided a useful and simple approach to characterise the transformation and loss of information which occurred during the minute taking process.

Here, only one topic of conversation was chosen to illustrate typical minute taking practices that inevitably generate information loss. "Topic 4" was chosen for this purpose as it appears to have been badly recorded by the secretary; its map from the minutes implies it was not an important topic of conversation, while its map from the transcript suggests otherwise. Figure 5.22 presents both maps side by side. Each thread in the minutes' map has been referenced with a letter (thread A to thread E) and the corresponding conversation threads in the transcript map have been referenced accordingly to enable a detailed and explicit comparison of the information structure and content between both maps.

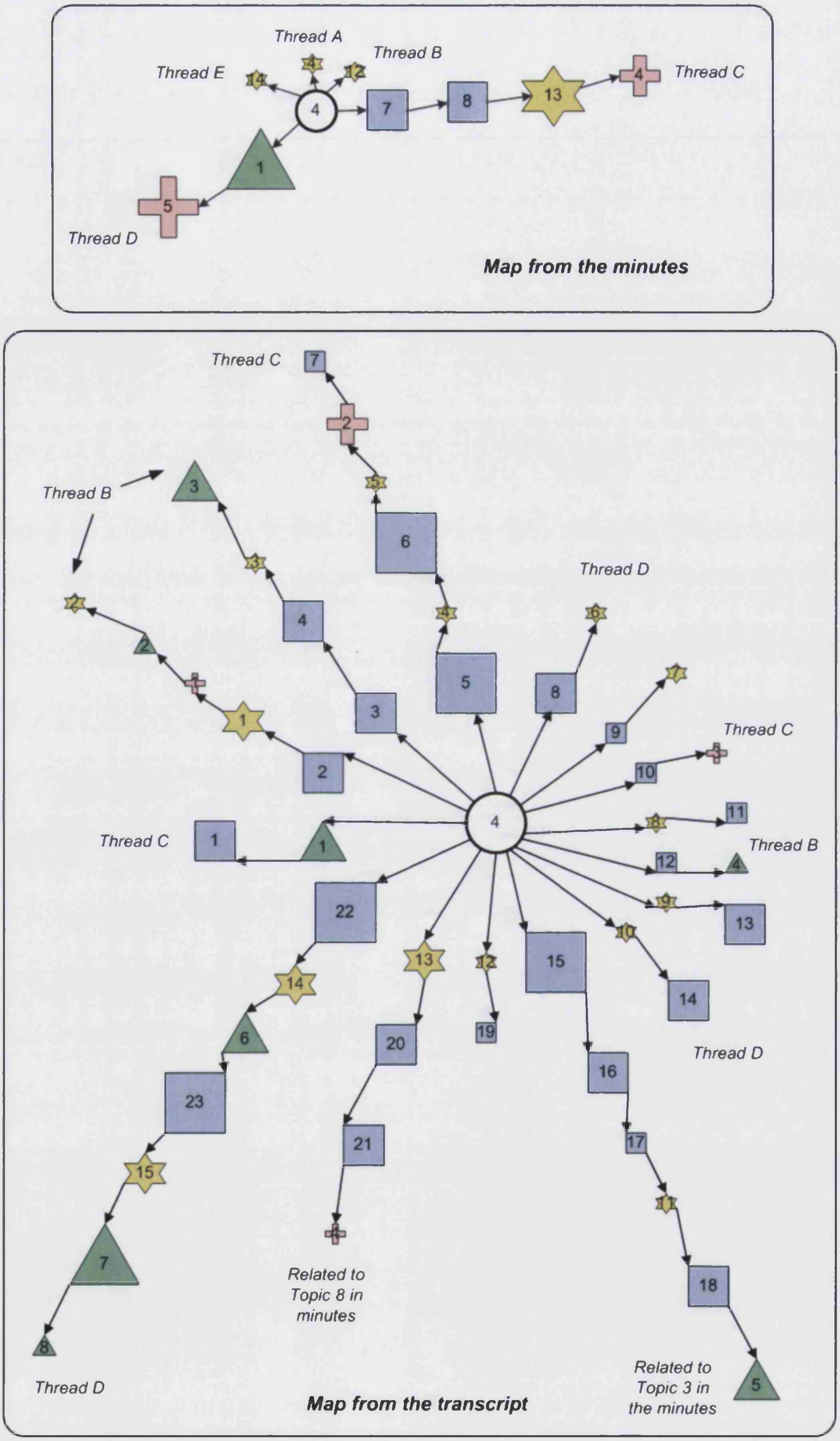

Figure 5.22 *Information maps for topic 4 in the minutes and in the transcript of the Airbus UK RR*

From the results shown in figure 5.22, a number of comments can be made:

- Threads A and E are not present in the transcript map. This information was added in the minutes to provide a coherent link between the sections in the document. Thread A relates the decision to focus on "topic 4"; this was of course driven by the agenda during the meeting and was therefore not part of the conversations reported in the transcript. Thread E closes the section relating to "topic 4" and this type of information is not expected to be made explicit during the conversation. Overall, the minutes are expected to contain "unspoken" information that essentially serves the purpose of giving context to the written account of the event.
- In the transcript map, 2 threads that relate to other topics in the minutes (i.e. topics 3 and 8) have been found. These are important threads and they demonstrate how "topic 4" was a key conversation topic in the review of the specifications document. The thread relating to a previous topic, i.e. "topic 3", essentially conveys rationale and even a lesson learnt for a decision taken at an earlier stage of the meeting. Nevertheless, if the reader refers to the map of the minutes for "topic 3" (appendix F), this thread is only very briefly summarised in this map, and most of the information concerning the rationale and the lesson learnt has therefore been lost. For the thread relating to "topic 8" in the minutes (see the topic map in appendix F), only the final decision/action has been reported in the minutes and all the rationale has therefore been lost. These examples show how the natural development of a conversation cannot always be represented in a written document.
- Threads B, C and D are present in both the minutes and the transcript maps. The common aspect of these threads is the transformation performed post-meeting by the minute taker: several conversation threads where summarised in a single information thread in the minutes. This summarisation or compilation process is expected and recommended; the minutes of a meeting is a summarisation document and therefore its contents must be to the point and avoid dispersing information related to the same issue across the text. Nevertheless, in the case of thread B, most of the information has been lost: rationale, lessons learnt, but even decisions and actions. On the other hand, thread C seems to have been properly recorded by the secretary. This transformation process is expected to generate some information loss, but the study also suggests a correlation between the importance of an issue and the number of threads that relate to it in the transcript map (e.g. thread D).

4.2.3. Detailed knowledge loss study for two critical meeting topics

In the minutes map (see appendix F), the most important topic in terms of number of words involved and highlighted knowledge items was "topic 5" and its map was therefore completely detailed both from the minutes document and from the transcript. In the transcript however, the two most important topics based on the same criteria were "topic 5" and "topic 4". As reported in the previously, this was quite a surprise as the minutes' map suggests that "topic 4" was not of great importance. Figure 5.23 compares both maps (transcript map and minutes map) for "topic 5".

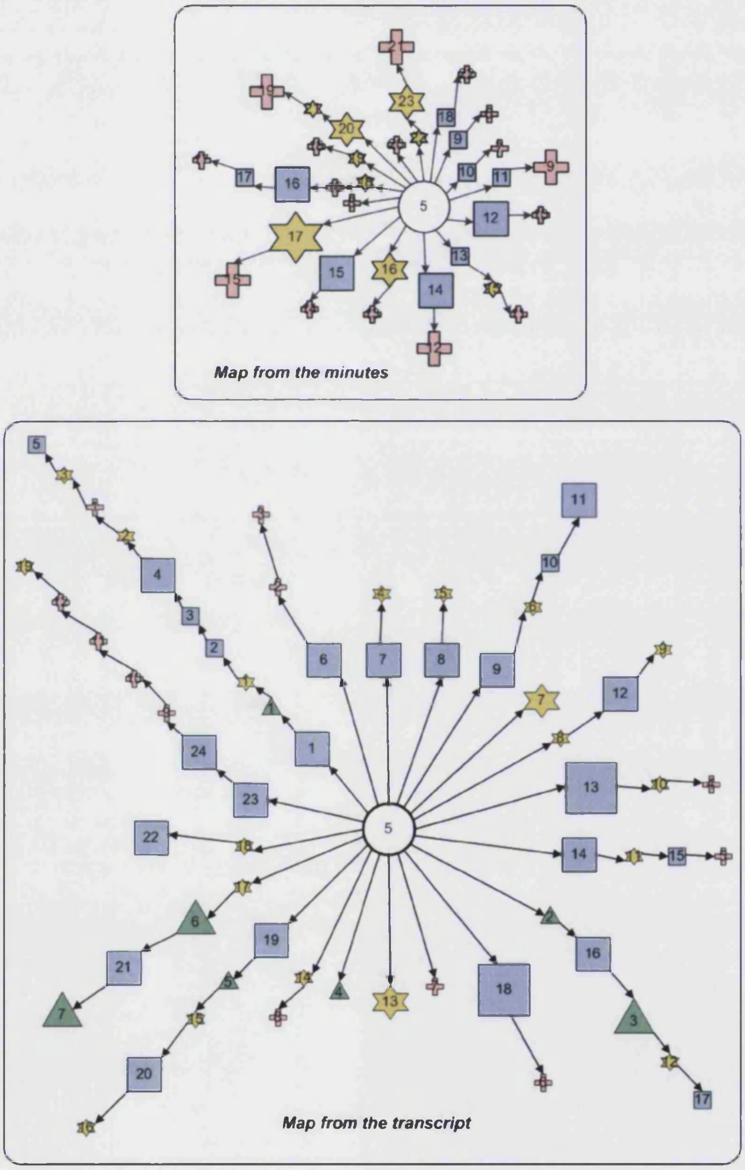

Figure 5.23 *Information maps for topic 5 in the minutes and in the transcript of the Airbus UK RR*

"Topic 4" (see figure 5.22), based on the detailed information loss study presented previously in §4.2.2, appears to have been badly recorded by the secretary. In the transcript map for "topic 4" a high number of threads, many rationale, decisions and lessons learnt elements appear but with few actions associated to these. On the other hand, when comparing the maps for "topic 5" it seems that the minutes give an accurate account of the discussions which took place. Looking at "topic 5", a different observation can be made immediately: it seems that when writing up the minutes, the secretary "transformed" some of the decisions into actions. This is perfectly understandable as decisions can always be interpreted as actions.

The single most important difference between "topic 4" and "topic 5" lays in the actions: in the discourse, most of the threads linked to "topic 4" do not contain actions, whereas it is quite the opposite in the case of "topic 5". The resulting difference in the minutes' maps suggests that it is easier for the minute taker to record the meeting when actions are set out following the decisions. A number of meeting management strategies, discussed in chapter 3, suggest that meetings need to be action orientated to become effective.

Another factor which might have an influence on the difference in the way minutes were taken for topic 4 and 5 is the "distance" observed between the conversations and the artefacts under review. Although none of the meeting analysis tools presented in this thesis are capable of providing data for this type of measurement, the observations made by the author suggest that the participants held discussions closely related to the document under review in the case of topic 5. This most definitely facilitated the secretary's work as he had an explicit reference to action any decision made. Topic 7 (see appendix 7) would be another good example that corroborates this idea; the discussions were closely related to the artefact under review (risk register) and the decisions taken during the meeting were immediately converted into actions in the minutes.

Finally, the four comparative criteria to evaluate knowledge loss outlined in chapter 4 can be further illustrated using the examples provided by figures 5.22 and 5.23:

- Volume and Length: these two criteria help to express the importance of a topic, knowledge element, or thread relative to the rest of the document. They were used as visual indicators of critical topics in the maps which warranted further investigations.
- Variety: from the examples given in figures 5.22 and 5.23, it can immediately be observed that the richness of the text based on the discourse is lost; actions and

decisions on one side and rationale and lessons learnt on the other are very often merged or transformed.

- Order/Sequence: With more data, research for typical patterns could be conducted. One of the conclusions based on this criterion is that in the document relating the discourse rationale is given before or after the decision or action, whereas in the minutes the sequence is invariably rationale then decision. Overall, the unstructured and unpredictable nature of speech is well reflected by the visual sequence provided by the IMT.

The essential finding that has emerged from the knowledge loss study detailed in this section is the importance of turning actions into decisions. Indeed, the secretary seems more capable of recoding the associated rationale, lessons learnt, and decisions based on an explicit expression of the action to be taken. The detail $IDEF_0$ process-oriented model described in chapter 3 (§2.2) accounts for the transfer of rationale and lessons learnt between design review activities. The model, however, does not show these key knowledge elements transferred as outputs of the design review process. Hence, the next chapter will investigate in more detail current minute taking practices in the aerospace industry and forward crucial improvements based on an action-oriented recording strategy to force rationale and lessons learnt out of design reviews.

CHAPTER SUMMARY

The results collected from the DTM case studies have been compiled according to three analytical perspectives: the communication processes observed, the information processes detected, and the knowledge lost from the meeting records.

The TCS and the MCT, applied respectively to the Airbus UK case study and the CAMAQ project case study, provided the necessary features to detail and analyse the communication and information processes observed during the recorded design reviews. The IMT was used on a specific meeting, the Airbus UK Requirement Review, and the results generated enabled a comprehensive analysis of the knowledge lost during the event based on a comparison of the minutes and the transcript.

The observed communication structure of the recorded design reviews has been analysed at different levels. The study of the role of the participants in both case studies clearly illustrates specific communication patterns for the meeting as a whole; the results show the predominance of interface negotiation scenarios such as "justifications" and "information requests" scenarios during design reviews. When the detailed structure of speech in a design review situation is considered, the "intervention type" coding element of the TCS has helped to outline an interesting trend in the structure of spoken discourse verified in both Airbus UK design reviews: questions are often hidden in a more global statement and even when explicit they are only occasionally answered directly by a straightforward answer. This aspect explains the failure of certain established design rationale capture techniques, such as IBIS, when applied to spoken discourse. Indeed, these techniques are focussed on "question and answer" sequences aiming at unveiling the rationale in the conversation.

In order to analyse *the underlying communication intent*, the results from the "exchange roles" coding element in the TCS and the MCT have been studied in detail. Overall, the striking aspect common to all the design reviews monitored is the importance of "informing" and "clarification" communication activities (these roles occupied 60-70% of the conversations). These results suggest the "sharing information about the design" activity in the process-oriented design review model proposed in chapter 3 (§2.2) is key in the overall design review process. Of course, "decision making", "exploring", and "evaluating" are also key exchange roles observed during design reviews. Their variation in percentage of conversation time across different design reviews, as observed during the CAMAQ project case study, can easily be related to specific objectives of each design review type. Moreover, this means that the "evaluate the design" and "manage the design" activities proposed in the process-oriented model (see chapter 3, §2.2) will see their importance vary according to the position of the design review in the product development process; in the case studies, conversation related to "evaluating" peak around PDR, while "decision making" peaks in the early stages of the design process.

In the study of communication processes, a specific process has been chosen for detailed analysis: *decision making patterns*. This observation was made for the Airbus UK case study. The data generated from the "exchange role" criterion in the TCS, has enabled to outline typical sequences of exchange roles prior to decision making; 6 main sequences of decision making have been unveiled. These sequence patterns ultimately reflect a rational course of decision making with few conflicts of interest between participants.

The "origin of the topic of conversation" coding criterion in the TCS has further supported the qualification of *the level of structure of the information exchanged* during design reviews. In effect, the measures resulting from the Airbus UK case study indicate that 60-70% of the conversation topics are predetermined by the meeting agenda and the remaining topics of discussion are directly derived from these. From this study, the author would also have expected a higher percentage of totally unexpected conversation topics in the early stages of the product development process, but the influence of the artefacts used in the conversation seem to play an important role in the structure of the communication process.

The content of the information shared between participants, in the case of the CAMAQ project, were very much in line with Concurrent Engineering practices outlined in chapter 1 (§1.12). Design issues were at the heart of most conversations throughout the 4 design reviews monitored, with a peak at PDR. Management issues were dealt with early in the project (peak at RR), while manufacturing issues were only the true concern of the participants at CDR (with a critical low point at CR). The "domain of competence" coding criterion in the TCS has provided useful insights into the specific topics discussed during the two Airbus UK design reviews. The results show how in both cases "project management and business" and "certification and testing" were topics at the forefront of the discussions that took place.

The study of the types of information exchanged during the design reviews of the CAMAQ project has provided a unique illustration of the shift in balance between process and product information that occurs during the evolution of a design project. Process information dominates the topics of conversation in the early stages of the project and then slowly diminishes, while product information gradually increases to dominate the topics of conversation at CDR. This study is unique in the sense that it actually provides figures based on case studies to support claims made by other researchers, reported in chapter 2 (§4.3.1), on the shift between process knowledge and product knowledge across the life of a project. Nevertheless, the results from the DTM case studies show that the balance between product and process information remains within a 40%-60% bracket. This trend means that overall process and product information are shared in large amounts across the life of a project, and systems aiming at capturing this design information should focus on a hybrid approach (feature-oriented/process-oriented, see chapter 2 §4.3.1).

The study of the types of artefacts used during both Airbus UK design reviews clearly suggests that they are important elements which structure and focus to a certain point both the communication intent and the type of information exchanged between the participants. Artefacts used during a design review have definitely a key role to play in the elaboration of improved techniques for the efficient capture of meeting contents.

Finally, the interpretation of the results from *the knowledge loss study*, carried out using the IMT on the minutes and the transcript of the Airbus UK RR, has inspired the definition of an action-oriented strategy for minute taking. Indeed, the secretary seems more capable of recoding the associated rationale, lessons learnt, and decisions based on an explicit expression of the action to be taken. The next chapter will therefore further investigate current practices in minute taking and propose a general knowledge-based strategy to improve design review records.

CHAPTER 6

A KNOWLEDGE-BASED STRATEGY FOR DESIGN REVIEW RECORDS

So far, this thesis has established means to analyse and understand the communication, information, and knowledge mechanisms involved during meetings, focussing on design reviews. The results from the case studies, detailed in chapter 5, support and illustrate the theoretical views on design reviews: they are critical events in the design process where important knowledge is created and shared, but subsequently lost during the recording process. This chapter therefore focuses on minute taking practices currently deployed in the aerospace industry. A study of design review minutes provided by Airbus UK and a survey on minute taking in the aerospace industry highlight current trends and pitfalls in the recording of meeting contents. Based on these findings, an action-oriented strategy to efficiently capture the important knowledge elements from design review discourse is proposed. The strategy is supported by a "design review capture template", practical guidelines, and a detailed insight into possible computer based applications.

1. A STUDY OF MEETING MINUTES USED AT AIRBUS UK

The previous chapters have predominantly focussed on the communication and information exchanges which occur during meetings. However, the knowledge loss study, presented in chapter 5, has started to investigate the contents of the main design review output, the meeting minutes. It is now important to complete and further the study of meeting recording practices in order to suggest solutions for the improvement of design review records.

To this effect, this section will present a set of 4 design review record documents collected at Airbus UK. The comparative analysis of their inherent structure and underlying communication intent will establish certain characteristics in their composition.

1.1. The set of collected documents

Along with the meeting minutes of the two Airbus UK design reviews monitored for the purpose of this research, 2 other meeting record documents were provided by Airbus UK. Table 6.1 summarises each document by indicating its associated meeting type, its general format, and the Airbus domain of competence involved.

***Table 6.1** Summary of the meeting record documents collected at Airbus UK*

Reference number	Meeting type	Format	Domain of competence
1	RR (Airbus UK case study)	Standard presentation page, rest of document has no imposed structure	Systems
2	PDR (Airbus UK case study)	Standard presentation page, rest of document has no imposed structure	Systems
3	Wing configuration review	Standard presentation page, rest of document has no imposed structure	Aircraft configuration
4	Design review	Template for review report, includes guidelines to complete document	Systems

In table 6.1, the 4 documents are examples of design review records; documents 1 to 3 are design review minutes and document 4 is a template for review reports which integrates the design review minutes.

The following section will therefore examine in greater detail the structure and communication intent of these 4 meeting record documents.

1.2. The structure and communication intent of the documents

The three design review minutes presented in table 6.1 (documents 1 to 3) present a number of commonalities. All 3 documents have identical opening pages; a cover page followed by an "archiving information" page.

The cover page compiles document information, i.e.: the company name and logo (in this case Airbus), a document reference number, a reference number to the part/module/product under review, the issue number, the number of pages, the document title, a summary, the subject of the review, the aircraft programme number, the distribution list, the signatures of the employees responsible for the contents of the document (author/secretary, technical approval, technical authorisation, and the product authorisation), and the copyright information.

The "archiving information" page includes the document history (detail of the authors involved and number of versions) and the document configuration information (office package used to write the minutes, document file location, any attached documentation).

These first two pages are used to store, locate, and retrieve the design review minutes within the relevant database. The document reference number, the date, and the issue number are repeated on each page above the page number across the entire document.

Another common section, besides the opening pages of the 3 documents, was the inclusion of the attendees' list at the start of the design review minutes. All these aspects are recommended in most meeting management and minute writing guides mentioned in chapter 3, and are sometimes referred to as the "housekeeping details" of the document (e.g. Markel 1994).

The general communication structure of the documents followed a similar pattern: the information was structured around the agenda of the meeting summarising each generic discussion topic using salient comments, proposals, actions, and decisions. Nevertheless, the specific information structure within each agenda item reproduced in the minutes varied considerably from one document to another. Table 6.2 sums up the observed differences for the 3 design review minutes in terms of decisions, actions, lessons learnt, and attached artefacts. As demonstrated in chapter 5 with the knowledge loss study, minute taking might imbed some of the rationale in the text, but this knowledge element is not expected to be clearly highlighted by the structure of the minutes observed and was therefore not included in table 6.2.

Table 6.2 Comparative table for the 3 Airbus UK design review minutes

Reference #	Observation criteria
1	**General observation:** the minutes start with an introduction and objectives. Then, the sections follow the documents under review. The format varies a lot, with some documents commented using open text and others using a table format, where each entry refers to a specific place in the reviewed document. **Decisions:** not highlighted in the text, often mixed with rationale and actions. **Actions:** clearly highlighted in the text with reference number, owner, and due date. One of the reviewed documents was not "actioned". No action summary. **Lessons learnt:** no lessons learnt summary. A couple of lessons learnt imbedded in the text. **Attached artefacts:** one of the reviewed documents (original version).
2	**General observation:** the sections follow the sequence of the main meeting topics. For each topic a summary is made followed by a comments/actions sub-section. **Decisions:** supplier decisions are outlined in each summary. Then, final Airbus decisions are imbedded in the comments/actions sub-sections. **Actions:** associated to each decision or comment when relevant. Actions are compiled in a summary table at the end of the minutes with a reference to the sub-section number, name of owner, and due date. **Lessons learnt:** none. No summary. **Attached artefacts:** copy of the supplier's presentation slides in appendix.
3	**General observation:** the text is composed of a summary for each review topic following the meeting sequence, briefly outlining the main decisions, rationale, and conclusions. Then, in appendix, important comments and decisions are reviewed through a "questions & answers" type text that follows again the sequence of the meeting. **Decisions:** imbedded in text, not highlighted. **Actions:** summarised in the final section, but never explicit in the summary of reviewed topics or in the "questions & answers" appendix. Only a brief summary of the action and the department concerned are given. **Lessons Learnt:** some imbedded in text, but not highlighted as such. Often a mix of information, rationale and lessons learnt in the summary part. **Attached artefacts:** none.

The specific communication intent for each one of the 3 documents analysed in table 6.2 also varied significantly. While documents 1 and 2 clearly focus on communicating decisions and actions, document 3 essentially reports on the shared information and the debates that took place during the meeting.

The study of document 4, the review report, adds an interesting perspective to the analysis of the 3 aforementioned design review minutes. As previously stated in this thesis (chapter 3, §3.2), it is standard practice at Airbus for review minutes to be included in a comprehensive design review report. Document 4, referenced in table 6.1, is an explicit and structured template for review reports where each section comes with a brief set of guidelines to help the author complete the report correctly. The template is composed of the following parts: a cover page followed by "archiving information" pages nearly identical to the ones found for the review minutes, a table of references, the review purpose, the review contents (meeting agenda and presentation slides), the reviewed documents list, the attendees list, a section to paste the review minutes, and a section to paste the discrepancies and actions tables. The review report therefore seems to summarise and bring the centre of attention to actions, decisions, issues, and artefacts. The brief guidelines in the template related to the insertion of the meeting minutes suggest that the author should focus on outlining the context for each action, decision, or issue raised during the meeting. In this respect, it would therefore seem that document 3, by providing more context and information about the decisions and actions taken during the design review, is more in line with the company's expectations than the two other examples. However, it is important to note that it is not possible to be sure that minutes of design reviews are always inserted in a review report. This claim is supported by the fact that all three examples of design review minutes presented in table 6.2 contain a detailed cover page and precise archiving information; as a stand alone document, document 3 is definitely less structured than the two others and its contents could even be qualified as "information overload".

Although it is impossible to generalise with only 3 examples of meeting minutes, this limited yet highly illustrative study offers an opportunity to outline a few observations about minute taking practices in the aerospace industry:

- Actions, decisions, and issues are the main information elements that engineers and their companies want to put forward in the design review minutes.
- The contents of the minutes instinctively follow the structure of the meeting agenda.
- Overall, the meeting minutes document presents itself in a semi-structured format, but within this framework the contents are unstructured and vary according to the secretary.
- The lack of precise guidelines for minute taking is most probably to blame for the observed information overload and the repetitive nature of the communication intent.

2. THE MEETING MINUTES SURVEY

The previous section presented a specific view of design review minutes based on examples provided by Airbus UK. To further develop a precise understanding of minute taking practices in engineering design, a questionnaire was distributed to aerospace companies and suppliers based in Canada and in Europe. This survey aimed at establishing how engineers, working in the aerospace industry, use minutes in their activities and how their companies integrate them in their business/design process. In a first instance, this section will present the detailed results of the survey, and then a selection of comments made by engineers will complete the view of current engineering practices relating to the minutes of design reviews. This investigation is a unique opportunity to focus on the problems that aerospace engineers actually encounter and to help outline possible improvements which could be made based on their feedback. This section will effectively expand and refine the hypotheses made previously using widespread data from a variety of aerospace companies with respondents working in a diversified range of domains.

The initial questionnaire that was distributed in 2005 to around 10 different companies from the aircraft industry can be found in appendix G. Overall, some 50 engineers replied to a set of 17 questions. Most of the respondents studied engineering in the UK, Canada, or France, and are now practicing engineers in a variety of fields: advanced engineering, aerodynamics, airworthiness, knowledge and information management, manufacturing, project management, quality management, structural analysis, systems integration, etc. Overall, the primary activities in which the respondents are involved can be clustered as follows: 46% have a management role, 40% a design role, and 14% a manufacturing role.

2.1. Analysis of the results

This section will now present the detailed results of the survey according to three fundamental research aspects: company guidelines and practices for meeting minutes, typical structures of design review records, and the respondents' perception of meeting minutes. The results for each question will be commented briefly in the following paragraphs and, for the key issues highlighted by the survey, a chart will further illustrate the comments made by the author.

2.1.1. Company guidelines and practices for meeting minutes

A fundamental aspect revealed by the survey is that engineers are not trained to take minutes – 78% of respondents had received no formal training during their engineering studies. Engineering curricula rarely integrate this practical aspect of project management; the students are often loosely guided towards keeping a logbook and taking notes during team meetings.

Furthermore, figure 6.1 shows that it is not necessarily part of the company's policy to take minutes during meetings (based on question 4, appendix G). In the case of design reviews, which are formal meetings, only 43% of the respondents believed taking minutes was part of their company's policy.

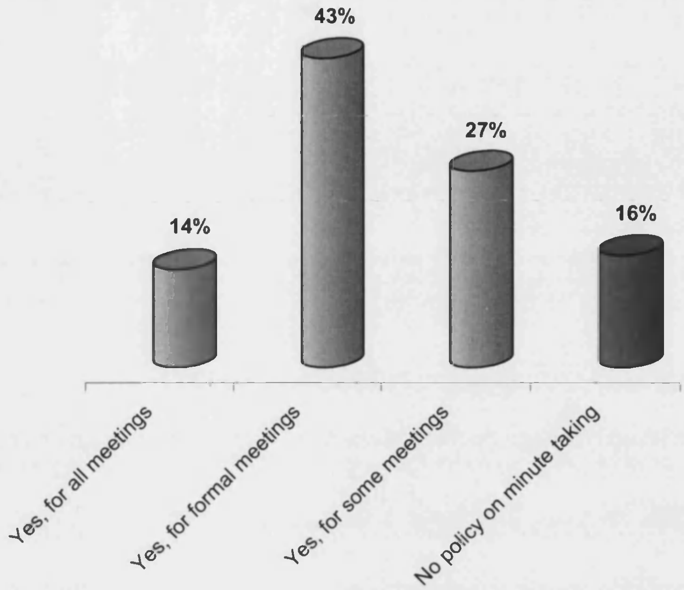

Figure 6.1 *Meeting minutes survey: is it part of your company policy to take minutes during engineering meetings?*

Figure 6.2 shows that only 41% of the respondents were aware of existing formal templates in their work environment (question 5, appendix G). When a template is available, the company prefers to provide a set of templates according to the domain of competence and meeting type (31%).

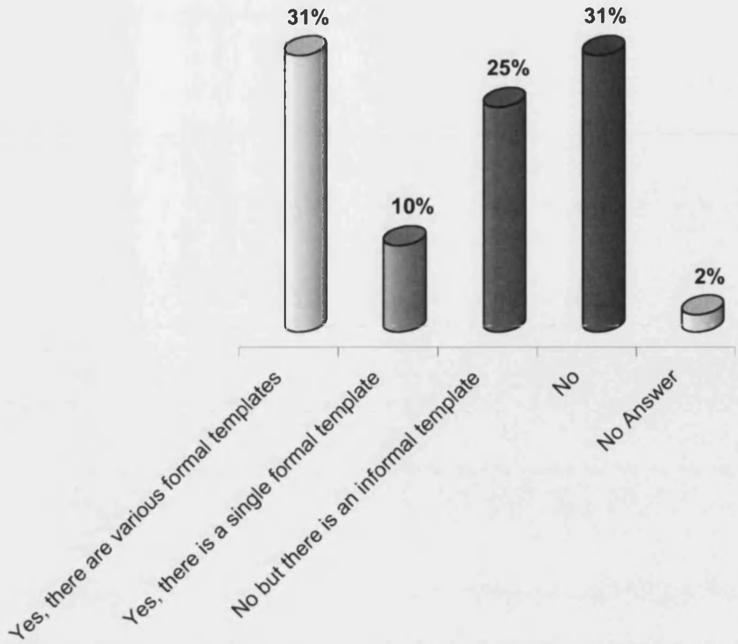

Figure 6.2 *Meeting minutes survey: does your company provide engineers with a formal minutes template?*

In terms of archiving practices (question 6, appendix G), the 3 main methods employed to store meeting minutes are in a document repository linked to the project (57%), on the author's computer (51%), and/or in a knowledge/information data store (25%). When suppliers are involved on a project (question 7, appendix G), the engineers agree that the minutes of the meeting are usually shared between the partners (63%). The usual time to issue the minutes of a meeting (question 8, appendix G) is about a week with only 4% of the respondents acknowledging the existence of standard company deadlines to issue minutes of meetings.

The overall impression left by this investigation into organisational guidelines and practices for meeting minutes is that companies provide an inconsistent support for engineers to efficiently capture the valuable information from design meetings. The lack of guidelines and tools strongly suggest that organisations view meeting records as a short term benefit; the archiving methods indicate that minutes are only really used during the life of the project.

2.1.2. Typical structure of design review records

Section 1 has detailed typical structural elements of design review records based on a number of examples provided by Airbus UK. The questionnaire goes a step further by seeking to outline the typical structure of meeting minutes across several companies and by assessing the sections that are actually of interest for practicing engineers.

The results from questions 9 and 10 (appendix G) of the survey, shown in figure 6.3, illustrate the sections usually found in meeting minutes and those which are most referred to by engineers in the context of their work. The actual list of sections was proposed by the author based on the observations made in the previous section of this chapter and on his personal experience in minute taking.

In general, the sections that typically constitute the minutes of a design meeting in the aerospace industry include: the list of actions, the list of attendees, the list of decisions, the agenda, the summary of topics discussed, the distribution list, and the objectives / aims of the meeting. Within this typical structure of meeting minutes only 6 of the previously mentioned sections are referred to by engineers; the distribution list is apparently not of any use for engineers. Of course, some of the sections of a document are not always of any use to the reader because their purpose lies elsewhere: they can answer archiving requirements for instance.

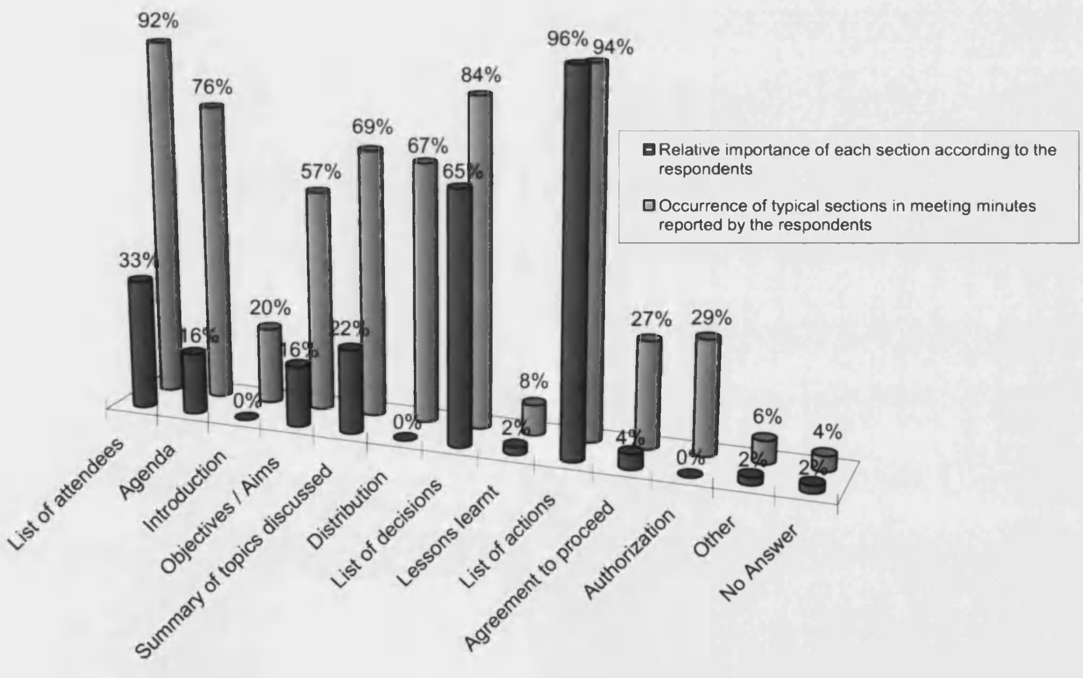

Figure 6.3 *Meeting minutes survey: occurrence and importance of typical sections of meeting minutes according to the respondents*

In figure 6.3, two sections stand out as very important: the list of actions (96%) and the list of decisions (65%). Engineers clearly focus on the results of the meeting rather than on the context, with the agenda, introduction, objectives/aims, and the summary of topics discussed well below the lists of decisions and actions. The relative importance of the list of attendees (33%) is a possible explanation for the method used by engineers to gather information about the context of the event: they can contact their colleagues who participated in the meeting.

2.1.3. The respondents' perception of meeting minutes

The final questions of the survey investigate the respondents' perception of meeting minutes based on personal experience. In question 11 (appendix G), the results illustrated in figure 6.4 show how only 31% of the engineers think minutes are kept for "legal purposes" when aerospace standards, i.e. SAE AS9100 (2001), clearly outline the legal implications of minute taking for companies working in the trade. However, the importance of actions is again highlighted in figure 6.4 where 96% of the respondents ultimately see minutes as a "formal reminder of actions to take".

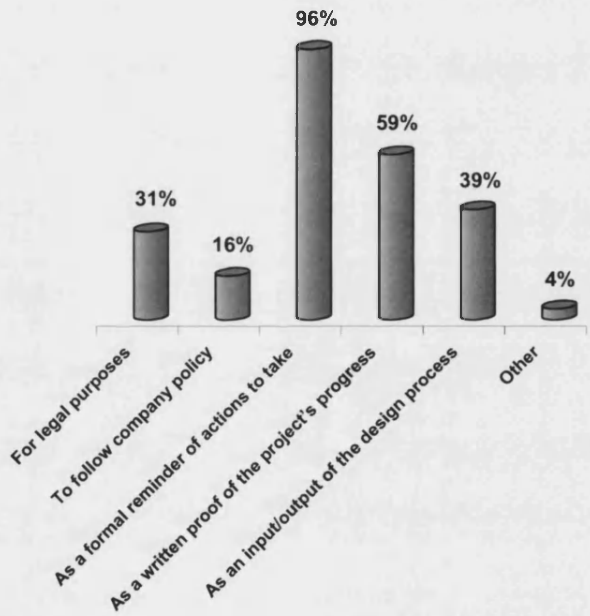

Figure 6.4 *Meeting minutes survey: for what purpose do you think minutes are kept?*

Question 12 (appendix G) is composed of 6 statements which the respondents had to qualify. From the results, it clearly appears that engineers think minutes have an important role to play in the design process (78% qualified this statement as "true" or "mostly true") and that they are specifically useful for project management purposes (72% qualified this statement as "true" or "mostly true").

On the other hand, the results illustrated in figure 6.5 show how engineers believe that current minute taking techniques provide a relatively poor record of design rationale and lessons learnt; only 30% of the responses valued the statement "minutes record rationale and lessons learnt as "true" or "mostly true".

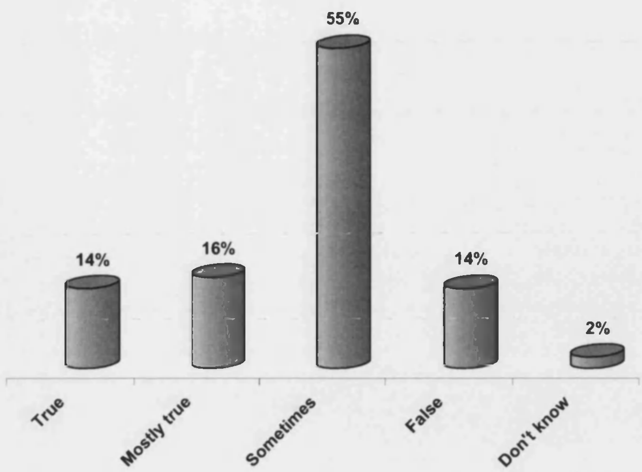

Figure 6.5 Meeting minutes survey: qualify the statement "minutes record rationale and lessons learnt"

Finally, figure 6.6 illustrates a crucial indecision amongst the respondents: should minutes of meetings be recorded by an engineer working on the project?

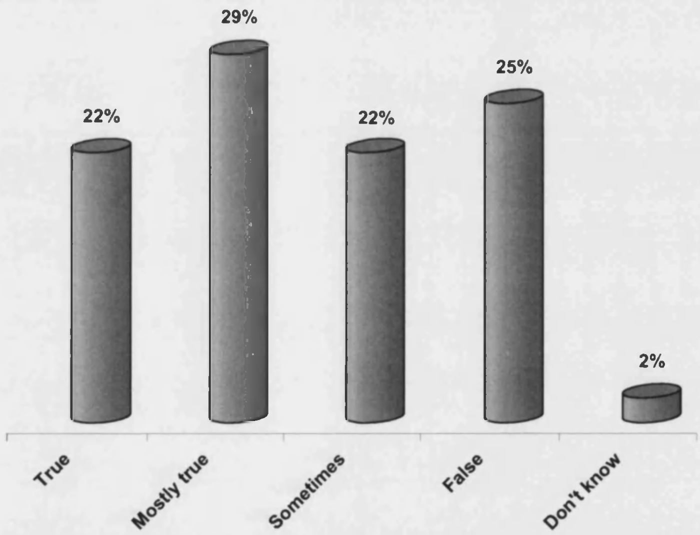

Figure 6.6 Meeting minutes survey: qualify the statement "It is important that the minutes are taken by an engineer working on the project"

From the author's point of view, in the case of aerospace design reviews, it is essential that the minutes of a meeting are taken by an engineer, but this person does not necessarily have to be working on the project. Indeed, from a communication process point of view, it is essential that meeting participants use common references to exchange and understand the information efficiently (see chapter 2, §2.1). It therefore also applicable to the person taking the minutes as it will undoubtedly improve the quality of the record. A secretary with a good understanding of the design issues discussed during the review coupled with training in the production of minutes should most probably be a priority in the list of requirements for the efficient capture of design rationale from reviews. Significant knowledge and experience related to the product and its development processes are major assets for minute taking activities; these are usually held by an engineer who has been working for a certain number of years in the same company.

2.2. Selected comments from the respondents

The results of the survey are unequivocal: engineers learn to take minutes by experience and only truly value the actions list, the practical side of traditional minute taking. They respect the role of meeting records in the design process, but are not given the right tools or training to take full advantage of the information richness of design reviews. The following comments made by the respondents in the questionnaire further illustrate the role of meeting minutes in the design process and key issues perceived by practicing engineers in the aerospace industry.

> *"Minutes are also used as a communication tool. The quality of minutes varies enormously."*

> *"Most engineers find it stressful if nominated to take minutes as no formal training is given. I would feel as if I would not be able to concentrate on the focus of the meeting due to worrying about failing to record an important decision/action. If an engineer is needed to take minutes (to understand the meeting rationale), it should be someone dissociated from the active involvement."*

> *"Minutes are essential for recording any meeting where a decision has to be made; it should give the logic and also the reason for the decision. They form part of the design selection process."*

> *"Usually we miss the chance to document design and decision rationale. Usually we discuss different alternatives but do not document why we have chosen a particular one. At a later point in time you are thus not able to revisit why a decision was made in a certain way."*

> *"Minutes have largely been overtaken in our organisation by action items. Instead of trying to record the minutia of the meeting the recorder documents decisions and actions to be followed up by attendees."*

3. AN ACTION-ORIENTED STRATEGY FOR THE EFFICIENT CAPTURE OF KNOWLEDGE ELEMENTS FROM DESIGN REVIEWS

With the review of current practices for minute taking in the aerospace industry completed in the two previous sections, it is now important to suggest alternative solutions to improve the capture of key knowledge elements from design reviews. In order to fulfil this goal, an action-oriented strategy is described in the next paragraphs. Then, a number of existing or future tools are detailed: a "design review capture template", design review guidelines, and an outlook into possible computer-based applications.

3.1. Description of the action-oriented strategy

The key aspect that has emerged from the meeting minutes survey is the importance of actions; the knowledge loss study, presented in chapter 5, also singled out "action taking" as a major factor towards the improvement of meeting minutes. In fact, the study showed that in certain cases the secretary would even turn decision points into actions in the final minutes of the meeting. Furthermore, the survey has established that even though engineers are not formally trained to take minutes, they instinctively focus on the actions from the minutes for the benefit of their work. Experienced project managers and meeting management guides (see chapter 3, §3.2 & §4.1.3) also suggest that meetings need to be action oriented to become effective. A number of alternative techniques for taking minutes are proposed by Markel (1994): verbatim minutes, narrative minutes, resolution/decision minutes, and action minutes. The latter solution was therefore the preferred choice in view of the results from the various studies reported in this thesis. However, as mentioned in chapter 3 (§3.2 & §4.1.3), publications in the field of meeting management are too often based on personal experiences and the recommendations made are rarely supported by an explicit rationale.

For this reason, the author decided to build an "action-oriented" strategy, described in figure 6.7, for the efficient capture of knowledge elements from design reviews. The strategy focuses on the overall knowledge process, from knowledge acquisition to knowledge implementation using a simplified version of the standard knowledge engineering life-cycle processes described in chapter 2 (§4.4).

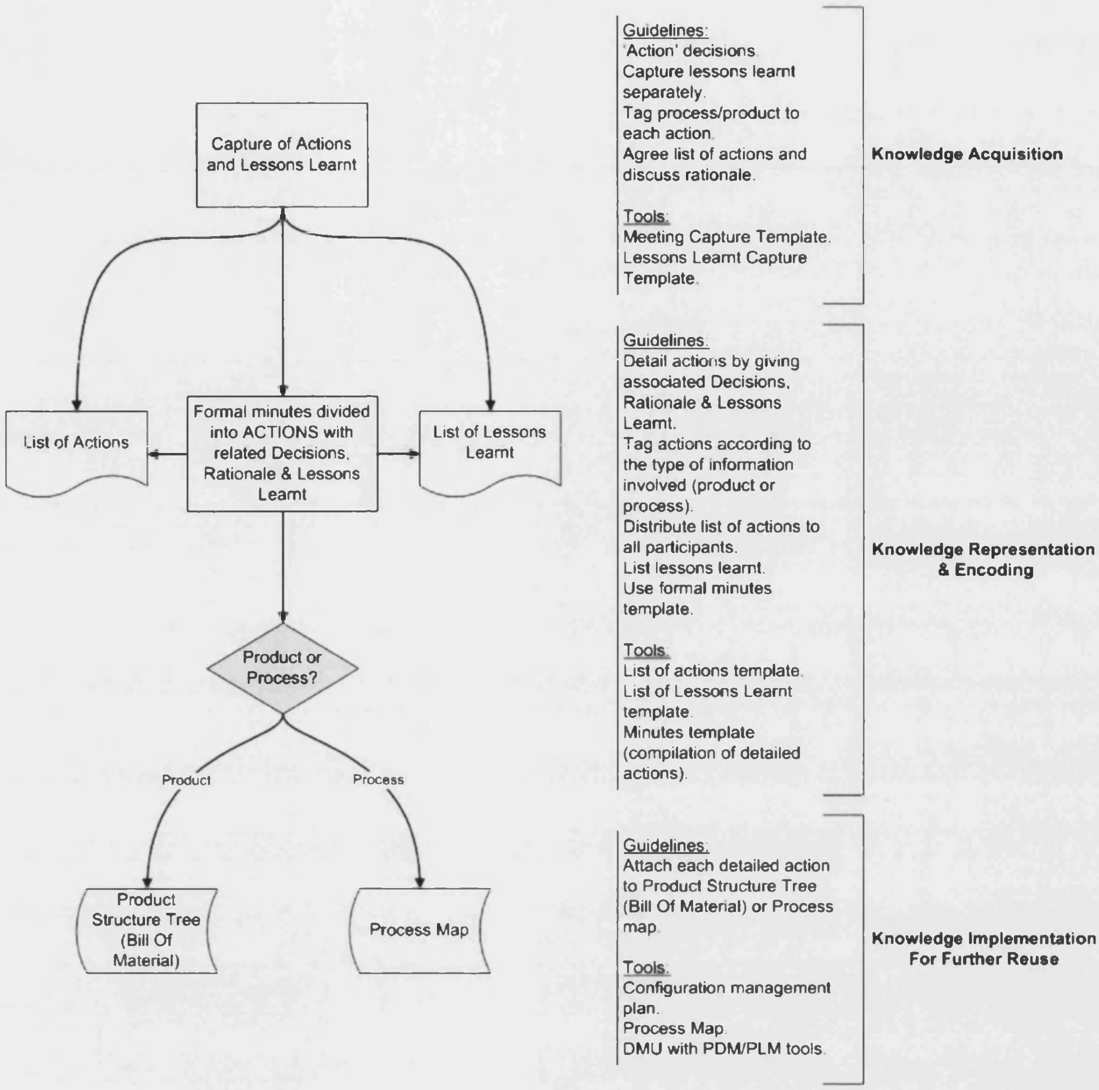

Figure 6.7 *The action-oriented strategy for the efficient capture of knowledge elements from design reviews*

The overall goal of the "action-oriented strategy" is to force rationale and lessons learnt out of the meeting by linking these elements to actions (or decisions), and then to make them readily available in the engineer's work environment. Although figure 6.7 aims to be self explanatory, its elements will be briefly summarised in the following paragraphs by focussing on the core objectives and implications for each step of the knowledge elicitation process involved in this action-oriented strategy.

Knowledge acquisition. Here, the tasks need to be performed during the meeting. The minute taker (secretary) should focus on the actions rather than the topics of discussion. When decisions are made, these should be "turned" into actions whenever possible. Then, for each action, memory cues such as keywords or links to artefacts should be taken into note so that the secretary can explicit the related topic of discussion, decisions, rationale, and lessons learnt during the knowledge representation and encoding process. In the action-oriented strategy, lessons learnt should also be tracked. To this effect, a separate "lessons learnt register" should be maintained by the secretary during the meeting. In certain cases, the lesson learnt will generate an action; therefore a link should be available between the actions and the lessons learnt. The knowledge acquisition tools developed to help the secretary capture minutes with the action-oriented strategy are detailed in §3.2.

Knowledge representation. Most of the activities involved in this step of the process could be achieved at the end of the meeting with the right tools and procedures in place. In order to explicit and effectively represent the knowledge generated during the design review in terms of actions, decisions, rationale, and lessons learnt, an important amount of time would need to be allocated at the end of the meeting to review in detail each action noted by the secretary. A proper review session will enable all the participants to agree and reflect on the rationale leading to each action. At the end of the meeting, the summary of the actions should be ready for distribution, so that the "owners" can start the work as soon as possible. Lessons learnt would also be reviewed and detailed in the same way. A separate form would be used to detail each action or lesson learnt; this form would be a stand-alone template with predefined sections to complete. The formal minutes of the meeting would therefore compile all the detailed action and lessons learnt forms. These could be grouped per meeting topic, outlined in the agenda. The formal minutes of design reviews often need to be approved by specific authorities; this document would therefore usually be finalised by the secretary after the meeting.

Knowledge encoding. Another critical activity which can be performed at the end of the meeting or post-meeting is the encoding of each action form. The objective here is to effectively tag each action according to whether it is related to product information or process information. The tagging process can be decided during the meeting between participants or post-meeting by the authorities approving the minutes of design reviews. As discussed in chapter 5, two other types of information are frequently discussed during meetings: external factors and resources. Nevertheless, these can easily be associated to product or process information as suggested in chapter 2 (§3.3). With this tagging process, the action form containing the related decisions, rationale, and/or lessons learnt becomes an explicit rationale item which can be linked to the appropriate engineering information management tools.

Knowledge implementation for further reuse. The final stage of the action-oriented strategy aims at making the minutes of the design review available to engineers through existing CE information and knowledge management tools (see chapter 1, §1.1.2). For example, once each action form is tagged and validated by the authorities, it can be integrated in one of two major tools used on a daily basis by engineers and project managers: Product Data Management (PDM) software or a process map. In the case of the PDM, the action form tagged as product information could be attached in the Product Structure Tree, also known as the Bill Of Material (BOM), as an "action file" at the product structure level involved in the action. In a similar way, an action tagged as process information could be linked to the associated activity box in the project's process map. Process maps, also known in some companies as "roadmaps" (not to be mistaken for a "technology roadmap"), are often used as process rationale and prediction tools by project management teams. This novel approach bi-passes the creation of a separate "knowledge management tool for design meetings" and uses instead current engineering tools and technologies widely deployed in the aerospace industry. The engineer does not have to use a separate and unfamiliar interface to seek the information he or she needs; with the action-oriented strategy, the assignments and their rationale are immediately available in the engineering work environment. For this knowledge implementation step to become operational, configuration management procedures and guidelines need to be customized. Figures 6.8 and 6.9 illustrate respectively a BOM built during the CAMAQ project with Dassault Systèmes' PDM (ENOVIA VPM) and a section of the process map developed by the students.

Figure 6.8 clearly shows that the BOM integrates a variety of files: drawings, documents, and geometry data. This structure also dictates the final Digital Mock-Up (DMU) of the product. A customisation of the configuration management plan could easily integrate a feature to allow the attachment of action forms to the BOM. During the life of a product, several BOMs are maintained, e.g. an engineering BOM and a manufacturing BOM, because the product can be seen from different perspectives. This is not a problem in the case of actions produced during design reviews: the related topic of discussion or "owner" will easily dictate the type (or types) of BOM involved in the action.

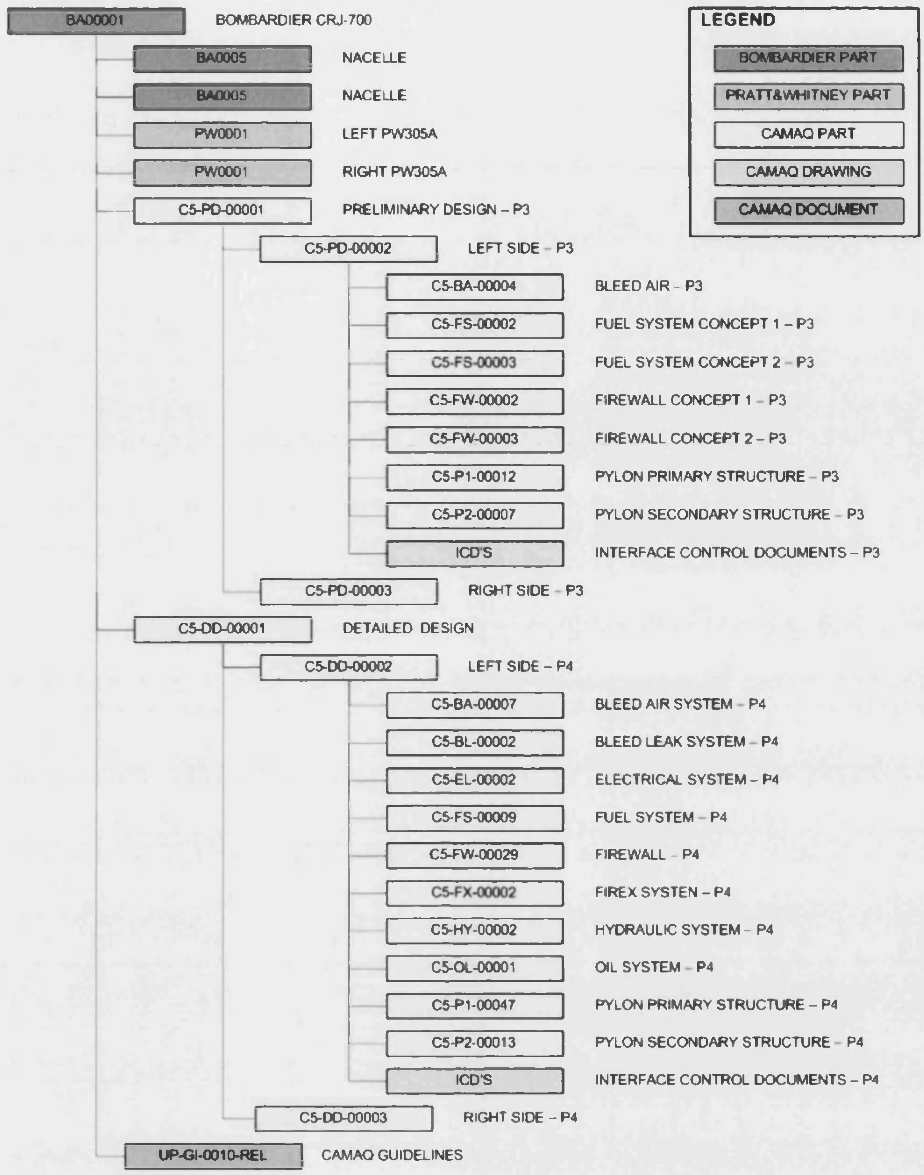

Figure 6.8 *A simplified version of the Bill Of Material for the new pylon developed during the CAMAQ project*

In figure 6.9, a section of the overall CAMAQ project roadmap has been reproduced. Here, the students decided to divide the process map between the different teams involved in the project. Only the first two engineering phases are shown in the figure (activities up to the CR) with only the top level activities; again, with this example, a straightforward link between the activity box and the action form (process information) could easily be created. Action forms would be inserted at any level of activity involved in the project.

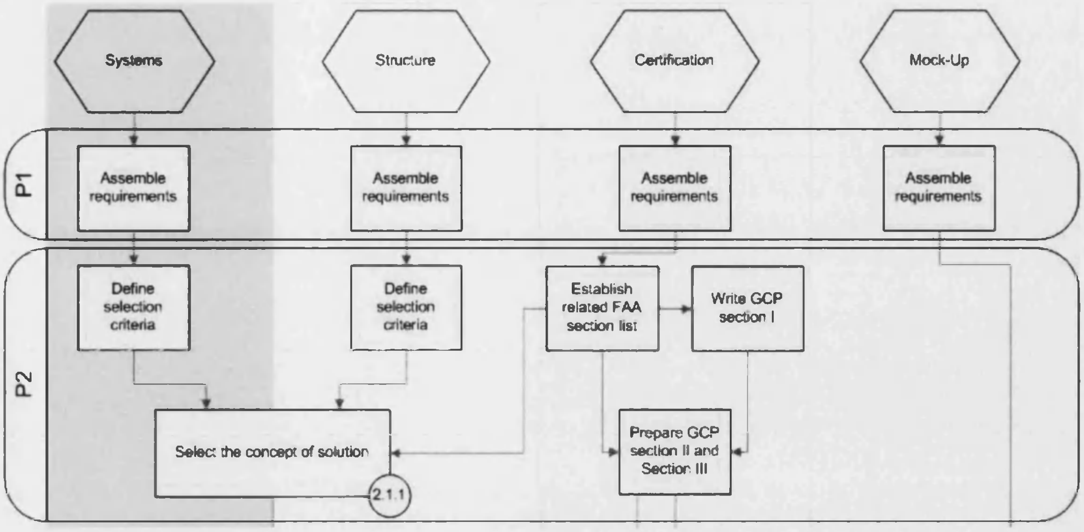

***Figure 6.9** The overall project roadmap (process map) for the first two engineering phases of the CAMAQ project*

The knowledge implementation step of the action-oriented strategy needs to be customised according to the engineering tools used in the company. Lessons learnt could be integrated in a similar way to the design environment, but ultimately more work would need to be undertaken to investigate ways of archiving the information so that it can be used across different aircraft programmes and shared between partners.

3.2. Focus on the knowledge acquisition stage of the "action-oriented strategy"

Within the overall strategy presented previously, the research efforts reported in this thesis have essentially focussed on detailing the knowledge acquisition stage of the process (see figure 6.7). The development of the knowledge representation, encoding, and implementation phases of the strategy (figure 6.7) require a close involvement of the interested parties, in this case Airbus UK, and important customisation and validation efforts to implement the new processes. This was unfortunately not in the scope nor the timescale of the research. Only a few preliminary tests have been carried out at Airbus UK by the KM team.

This section will therefore outline the latest developments and future expectations concerning the template developed to help the secretary capture efficiently the key knowledge elements of a design review. Along with this new capture tool, a number of guidelines have also been established. The action-oriented strategy recognises the need to capture lessons learnt; this aspect, however, is being developed internally at Airbus UK, in a separate research project, and will not be presented here to respect confidentiality agreements.

3.2.1. Developing the Meeting Capture Template

The Meeting Capture Template (MCT) described in chapter 4 was successfully employed to analyse the CAMAQ project case study. This template was therefore redesigned as a "design review capture template" to match the requirements of the knowledge acquisition process outlined in §3.1. The format of the template is identical to the MCT as the users found the table (or grid) display simple and comprehensible. Figure 6.10 shows the latest version of a blank "design review capture template" with 2 action entries. The column headings in grey are to be completed as the discussions take place, while those in white can be completed at the end of the meeting, during the review of actions.

Action #	Action (detail)	Why? (reminder of rationale or lessons learnt)	Who? (Initials)	Topic		Inofrmation type?	ID ref for process/ product tool
			When?	came from	detail (summary/ title/ #)		
1				□ Agenda item □ Slide □ Discourse □ Other		□ Process □ Product	
2				□ Agenda item □ Slide □ Discourse □ Other		□ Process □ Product	

Figure 6.10 *The latest version of the design review capture template based on the MCT*

Here, unlike the MCT, the second column focuses on the actions; space is provided for the secretary to detail in a few words the action to take. The next column is where notes on the rationale or simply a reference to a lesson learnt leading to the action can be inserted. The fourth column is where the "owner" of the action and the proposed deadline to carry out the assignment can be included.

The last column which must be completed as the meeting is taking place is the topic related to the action entry. The DTM case study analysis (chapter 5) has demonstrated that design reviews are well structured and will closely follow the proposed agenda. This means that most of the main discussion topics are known in advance. Artefacts used during meetings are another interesting source of information for the minute taker: they can help illustrate specific discussion points and serve as visual memory cues for the final editing of the meeting minutes. The topic column has therefore been divided into two sub-columns. A predefined set of categories (agenda item, slide, discourse, other) help the minute taker to quickly link the action to the contents of the discussions or an artefact under review. The next sub-column leaves space for the secretary to detail the topic in a few words or simply make a reference to a specific artefact (slide number, agenda item, document page, etc.).

At the end of the meeting, during the review of actions, the final two columns can be used to tag each entry in the "design review capture template" according to its information type and its proposed reference destination (in the BOM or in the process map).

Figure 6.11 illustrates the first version of the "design review capture template", which was completed by the author during the initial trial. The notable difference with the latest version (figure 6.10) is the order of the columns; in the latest version, the "Why? (Reminder of rationale)" column was moved to the left with the columns to be completed during the meeting, because the author found this configuration easier to use.

Action #	Action (detail)	Who? (Initials)	Topic		Why? (reminder of rationale)	Impact?	ID ref for process/ product
			came from	detail (summary/ title/ #)			
13	The pylon must be attached in the same way	S	☑ Discourse ☐ Agenda item ☐ Slide ☐ Other	Angle & Positionning of Pylon	Wrong statement on slide RD 200008 Engine properly checked	☐ Process ☑ Product	
14	Check BM 90000 for fasteners if not ask B	S	☐ Discourse ☐ Agenda item ☑ Slide ☐ Other	RD 20009	preferred use of fasteners	☐ Process ☑ Product	
15	Stick to MPS standard	S	☐ Discourse ☐ Agenda item ☑ Slide ☐ Other	RD 20010	The BAPS is confidential	☐ Process ☑ Product	
16	Existing GE Design complies with BirdStrike		☐ Discourse ☐ Agenda item ☑ Slide ☐ Other	RD 20011 Birdstrike	- Design is against Birdstrik. - Certification must prove it - keep same profile + design by similarity	☑ Process ☐ Product	

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Figure 6.11 The first version of the design review capture template

3.2.2. Guidelines for the effective use of the design review capture template

The "design review capture template" described previously was tested by the author during a student design review which took place at Ecole Polytechnique in 2005. From this trial, the following preliminary recommendations have been established. These guidelines focus on the role of the secretary and how to conduct the design review so that the template can be used to its full potential.

First, the role of the secretary (or minute taker) must be considered. They should be someone who:

- Is willing to assume the role and has experience of taking minutes in high level (aircraft product structure level) meetings/reviews. General trends in the knowledge loss study presented in chapter 5 (§4.1) indicate that the level of experience of the secretary has a significant impact on the quality of the minutes.
- Has good technical knowledge and is familiar with the progress of the project. An engineer with experience at aircraft module or programme level will possess a better understanding of the overall design process and activities; this will undoubtedly help this person to focus on the important aspects of a design review.
- Is not actively involved in any presentations or agenda items during the review. Remain neutral in order to provide an unbiased reporting of all topics raised. While experimenting with the MCT, it became obvious that when the student assigned to use the MCT was involved in a presentation during the review the resulting minutes were deeply affected.
- Shares authority with the meeting chair and is assertive, to clarify actions and gain agreement on potential lessons learnt. As shown in chapter 5, during design reviews, most of the time spent is to share information about the project and the product. It is therefore important that, in certain circumstances, the chair person and the secretary try to focus the discourse around decision making and lessons learnt. This will also prevent an extensive repetition of the information which was already available prior to the design review (in the data pack).

As stated previously and reported in meeting management guidelines (e.g. Streibel 2003), the way the meeting is conducted also influences the quality of the outcome. The following points observed during the "design review capture template" trial should be kept in mind:

- Stop and clarify if actions or decisions are unclear, with the same authority as the meeting chair.
- The majority of decisions should be transformed into actions and the rationale recorded.
- Focus on keeping track of actions and write a few words to record the rationale and discussion topic behind the action.

- Keep in mind whether something might be a potential lesson learnt, seek approval of the room and maybe nominate another participant to follow up at the time they arise.
- Time must be allocated to review and agree the list of actions and potential lessons learnt with focus on the rationale and 'owners'.
- Distribute the agreed list of actions as soon as possible – preferably at the end of the meeting or the same day.

The "design review capture template" and this set of guidelines are a first step towards a knowledge-oriented approach of design review records. As described in chapter 1 (§1.1.2), computer technologies are nowadays standard tools used for most of the engineering tasks involved in the development of an aircraft. Aerospace designers work in a digital environment; they develop a digital product using PLM and DMU technologies and are often part of a virtual team, which communicates through Internet or videoconference settings (Chapter 3, section 4). In order to efficiently integrate the action-oriented strategy to this digital environment, a future outlook into possible computer-based solutions for the capture of design review contents will be presented in the next section.

3.3. Future outlook: computer support for the action-oriented strategy

Based on the template presented in §3.2.1, which was initially designed as a paper based document, a more sophisticated approach can be envisaged where the secretary would be supported by a "design review capture software". Because of the growing number of digital artefacts used by engineers on a day to day basis, there is a strong case for meeting recording tools to efficiently integrate them for the purpose of minute taking.

The setting for computer support outlined by the author in the following paragraphs, however, does not seek to automate the knowledge life-cycle process with speech recognition technologies or even video and audio streams. The action-oriented strategy clearly dictates human input for minute taking; text input via a human facilitator (the secretary) would remain the preferred option for the software to be accepted and used in industry. Other possible automated approaches for minute taking suffer not only from technological barriers (e.g. multi-speaker recognition), but also from a number of organisational barriers outlined in chapter 3 (e.g. the "big brother" syndrome, confidentiality issues, etc.).

Figures 6.12, 6.13, and 6.14 are visual representations of the features a software interface would require to fulfil the expectations outlined by the action-oriented strategy. These figures illustrate a conceptual outlook of a "design review capture software" prototype which could be developed on a Windows Operating System.

Figure 6.12 shows the main window of the interface. The window is divided into 4 screens: 2 summarisation screens to list the actions and lessons learnt, a viewer window to quickly access the digital artefacts under review, and an information screen which details file information on the uploaded digital artefact presented in the viewer (e.g. author, date, file type, location in the BOM, etc.). A number of shortcut buttons are displayed at the bottom of the window so that the user can rapidly activate windows and edit any item of the meeting minutes.

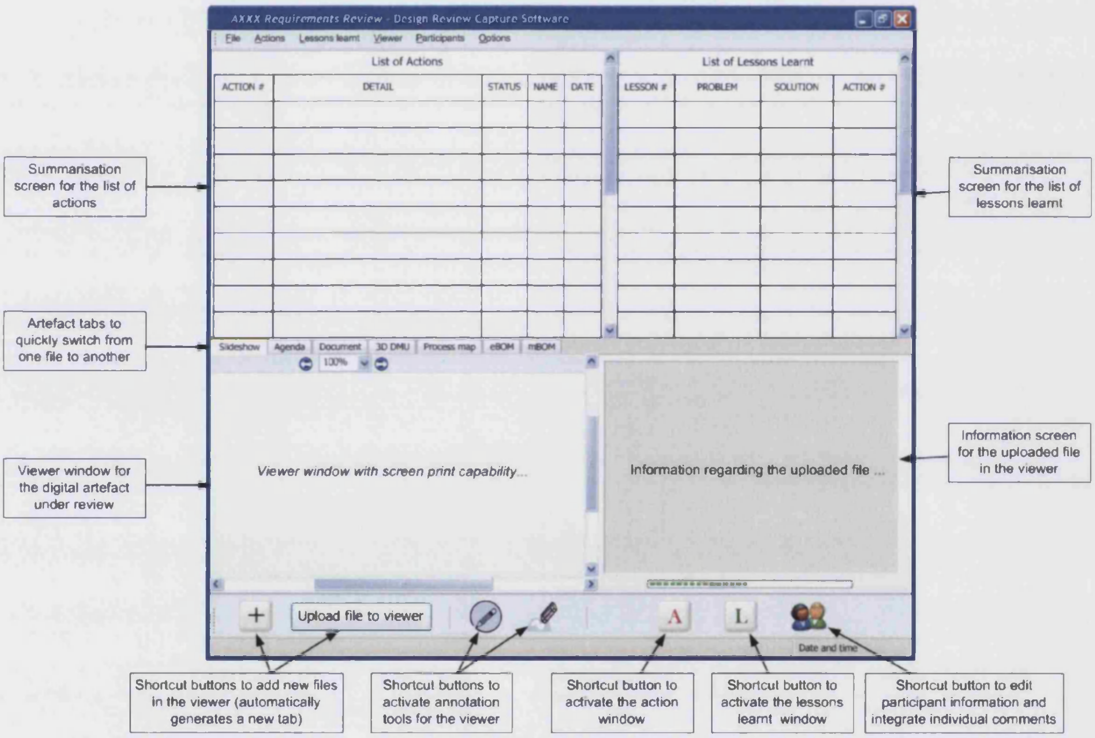
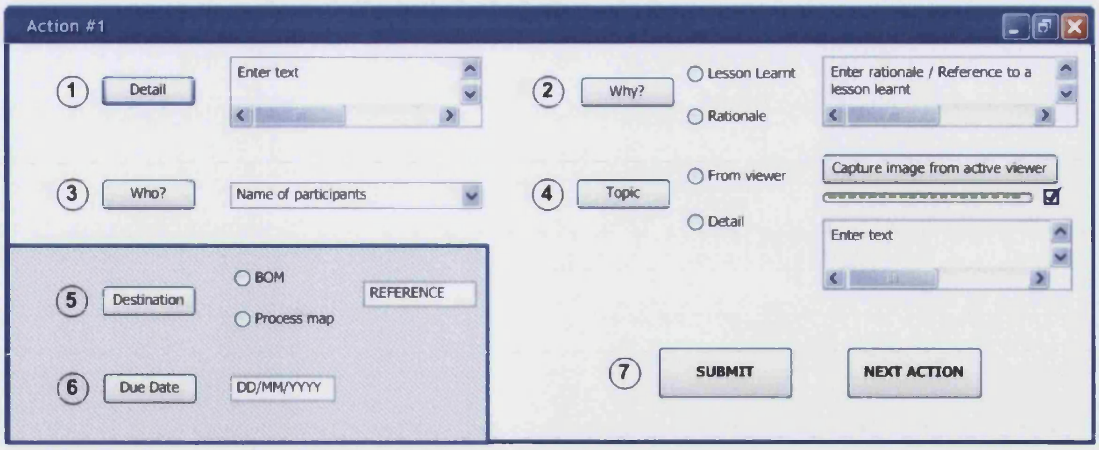


Figure 6.12 *The main window for the design review capture software interface*

The 3 shortcut buttons at the bottom right of the main window are directly related to the contents of the minutes; they enable the user to activate an "action window", a "lessons learnt window", or a "participant information and comments window". Figure 6.13 shows the concept developed for the action window.



LEGEND:

1- Text input to describe the action

2- Rationale for the action: text input for rationale or reference to a lesson learnt

3- Owner of the action ("actionee") from a predefined list

4- Topic related to the action: a screen print from the viewer to illustrate the topic and/or text input to describe the topic

5- Information type tagging: an action tagged as product information will be associated to a BOM, an action tagged as process information will be associated to a project's process map (this box can be completed post-meeting)

6- Agreed deadline for action to be completed (this box can be completed post-meeting)

7- "Submit"= save form and close "action window"; "Next action" = save form and open new "action window"

Figure 6.13 *The action window for the design review capture software interface*

The action window presented in figure 6.13 is composed of 7 sections which need to be filled in by the user following the numbering proposed in the legend. The grey zone (over references 5 and 6 in figure 6.13) can be completed after the meeting. Section referenced 5 (figure 6.13) corresponds to the action tagging (knowledge encoding) activity explained previously in §.1. In section referenced 2 (fi gure 6.13), the user has the possibility to link the rationale of the action to a lesson learnt. The user can switch to another action by clicking on the "next action" button or can submit the action to the action list in the main window by clicking on the "submit" button. Of course, the action list on the main window must also be interactive: a click on any entry in the list will automatically pop-up the corresponding action window. Most of the sections in the action window are text blocs to be completed by the secretary, except for section referenced 3 (figure 6.13) which needs to be predefined by the user prior to the meeting to effectively create a scroll down list where several names can be selected for the same action.

One of the most important requirements of the “design review capture software” presented here is the integration of the digital artefacts used during the meeting. To fulfil this requirement, the “viewer feature” needs the technological capability to enable a vast number of different file types (e.g. PowerPoint slides, word documents, 3D Digital Mock-Ups, figures, PDM files, CAD files, etc.) to be uploaded through the “design review capture software” as “view only” files. The user would not be able to edit the files uploaded in the viewer, but with an advanced screen print capability, annotation features would be possible. The action window therefore integrates the option to attach a screen shot of the digital artefact under review in order to illustrate the related topic of discussion (section referenced 4 in figure 6.13).

Figure 6.14 shows the “design review capture software” interface with the action window activated and an image of the DMU of the pylon designed during the CAMAQ project in the viewer.

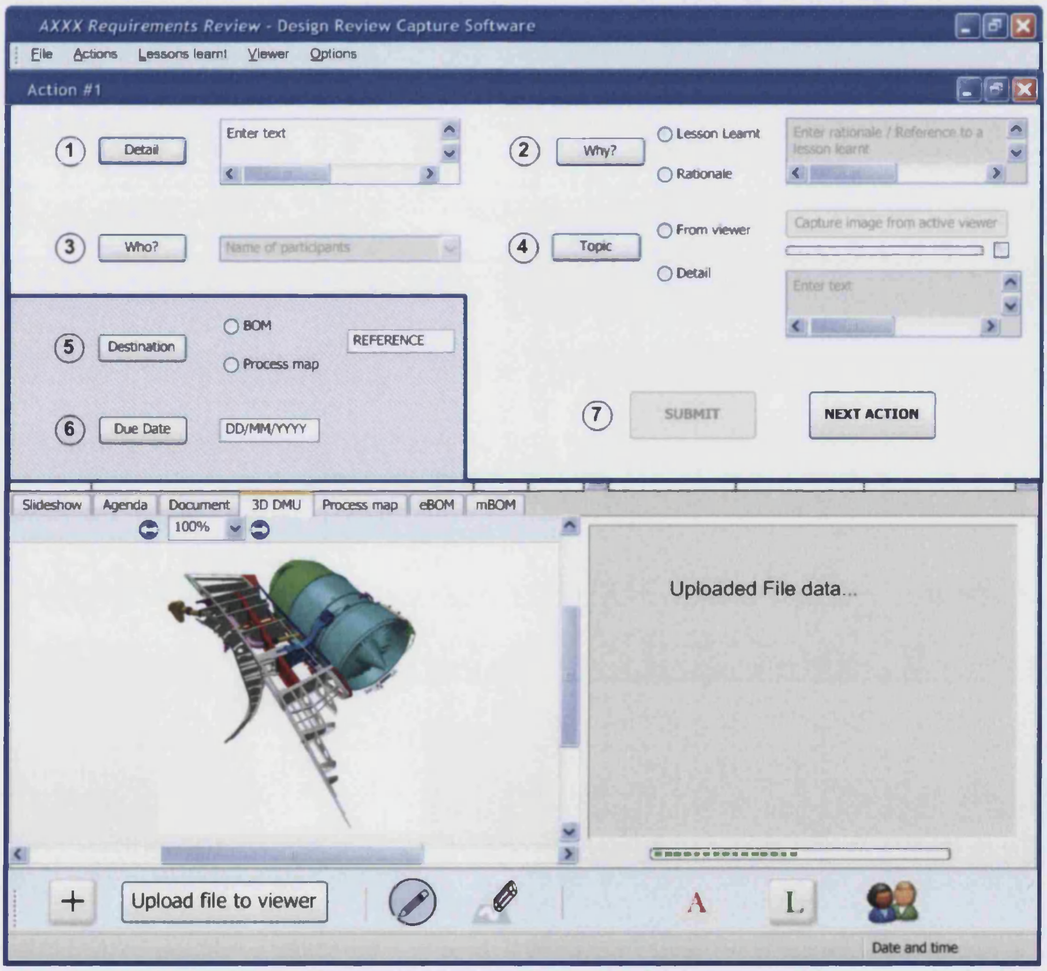


Figure 6.14 The design review capture software interface with the action window activated and a digital artefact uploaded in the viewer

The conceptual design of the software proposes an interesting approach for the user to quickly switch from the visualisation of one digital artefact to another: the integration of tabs above the viewer screen for each uploaded file. Finally, the window for editing lessons learnt would be very similar to the one presented here for actions, but has not been included in this thesis for confidentiality reasons.

By completing the various action and lessons learnt windows, the secretary would effectively generate action and lessons learnt forms, mentioned in §3.1; these would be standard office documents (based on a template) but their format would need to be customised to match company archiving requirements. In the case of an action form, the document would be comprised of the following main sections: description of the action, owner, date, description of the rationale, discussion topic with space for a snapshot from the viewer, a reference to the destination engineering tool (BOM or process map), and comments from the participants. Indeed, the integration of comments made by participants in the action or lesson learnt forms is another feature which would warrant further investigation. Computer technologies which incorporate handwriting recognition, namely the Tablet PC and the digital pen (see chapter 3, §4.2), offer promising capabilities for the efficient integration of personal notes to the formal minutes of a meeting (McAlpine *et al.* 2006).

Figure 6.15 illustrates a possible hardware set-up where each participant uses a digital pen so that individual comments can be included in the design review minutes via the action/lesson learnt forms generated by the "design review capture software". The setting is valid for meetings in both collocated and distributed situations. In figure 6.15, the secretary can use either a standard Laptop PC or a Tablet PC on which the "design review capture" software can run. The participants would use a formatted notepad, customised for the digital pen with pages following a similar structure to the "design review capture template" (§3.2.1). For the participants, the important feature to incorporate would be "private/public" functionality so that certain notes can remain private while others can be shared between the stakeholders. For an effective integration of the participants' comments to the action/lessons learnt forms, the review of actions seems an ideal opportunity to complete this activity.

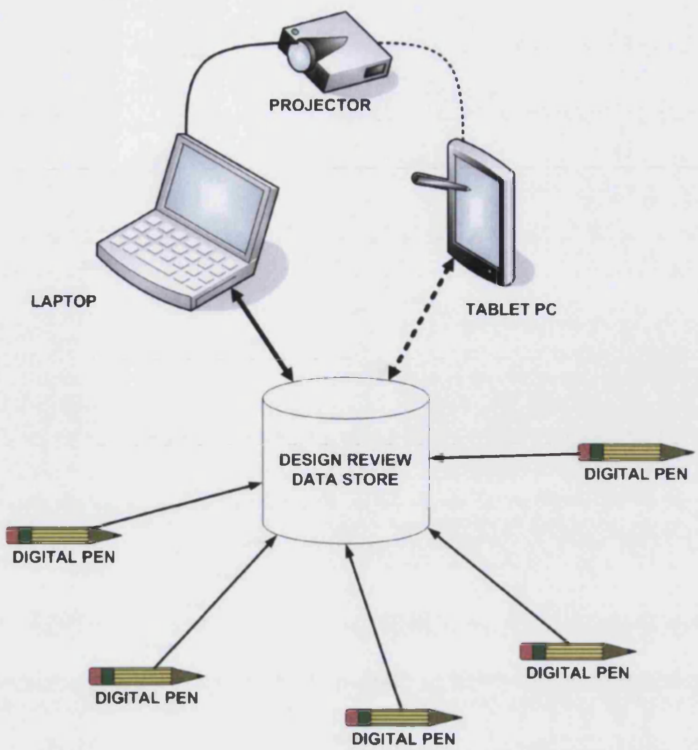


Figure 6.15 *Hardware set-up for the integration of personal notes to design review minutes*

The technological concepts presented here aim to integrate the core principles of the action-oriented strategy: actions are at the centre of the process with the aim of forcing rationale, lessons learnt, and decisions out of the design review information exchanges and integrating them straight into current engineering tools.

To put into practice the computer support solutions outlined in this section, a number of issues would require special attention: detailed technological solutions for viewer capabilities, links to engineering tools (PDM and process maps), hardware set-up, and meeting guidelines to enable the seamless integration of written comments from participants. Ultimately, the final “design review capture software” should be developed as an all inclusive solution; it should be able to perform all the activities suggested in the action-oriented strategy and therefore support the entire knowledge life-cycle process described in §.1.

CHAPTER SUMMARY

Four documents were collected at Airbus UK for a study of their structure and communication intent: 3 design review minutes and a design review report template. The template is effectively used to insert the minutes along with other meeting artefacts (e.g. agenda, copy of presentation slides, list of actions, list of attendees, list of reviewed documents, etc.). Overall, this study has highlighted that rationale and lessons learnt are not explicitly recorded in these documents, and although they propose a similar structure, the resulting contents are formatted in an inconsistent manner even within the same document. Comparing the 3 design review minutes with the design review report template has enabled the author to single out a major concern: the template generates significant information overload by recalling information which is already present in the minutes and in the same format (e.g. the actions list).

The study of a few examples of design review minutes limits the extent of the conclusions that can be drawn, and therefore a more precise understanding of minute taking practices in the aerospace industry was therefore sought via a survey. The questionnaire was distributed in 2005 to aerospace companies and suppliers based in Canada and in Europe. The investigation covered the following topics related to minute taking: "company guidelines and practices for meeting minutes", "typical structure of design review records", and "the respondents' perception of meeting minutes". The results of the survey are unequivocal: engineers learn to take minutes by experience and only truly value the actions list, the practical side of traditional minute taking. These findings resonate with the study of design review minutes at Airbus UK and with meeting management guidelines mentioned in chapter 3; meeting minutes must be "action driven" in order to be productive.

From the investigations into minute taking practices in the aerospace industry, the author has elaborated an action-oriented strategy to improve the capture of key knowledge elements from design reviews. This strategy can be described in 3 steps from the secretary's perspective:

1. First, during the meeting, the secretary should focus on keeping track of the actions with their associated rationale or lessons learnt. This knowledge acquisition phase of the strategy would see the secretary turn decision points into actions whenever possible, and at the end of the meeting sufficient time should be allowed so that each action can be reviewed in detail and agreed by all participants.

2. The closing stages of the meeting would effectively initiate the knowledge representation and encoding phases of the strategy; each action or lesson learnt would be detailed and tagged according to the type of information it contains (product or process). After the meeting, the secretary would finalise the formal meeting minutes by seeking the approval of the authorities responsible for the design review.

3. Once all the action and lessons learnt forms are approved, these can be linked to one of the two engineering tools used to manage product and process information. Actions tagged as "product information" could be inserted in the product structure tree managed by PDM systems, while those tagged as "process information" could be included in process maps or managed by workflow management systems. These operations would complete the knowledge implementation and reuse stage of the action-oriented strategy.

The action-oriented strategy is based on a variety of findings reported throughout this thesis:

- The different stages of the strategy follow standard knowledge engineering processes reported in chapter 2 (§4.4)

- The focus on actions is a direct consequence of the natural instinct engineers have to focus on actions, which has been illustrated through the knowledge loss study (Chapter 5, section 4), the study of design review minutes examples (chapter 6, section 1), the meeting minutes survey (chapter 6, section 2), and formal meeting management guidelines reported in the literature (e.g. Streibel 2003).

- A secretary will often naturally "turn" decision points into actions, as illustrated in the knowledge loss study (chapter 5, section 4). This behaviour should be promoted by the strategy, as it ultimately reduces knowledge loss.

- The resulting actions and lessons learnt captured from the meeting are tagged according to their information type (product or process related). This knowledge codification corresponds to current trends in the development of design rationale capture systems (see chapter 2, §4.3.1). The strategy even goes a step further by proposing to integrate the actions and lessons learnt to specific engineering tools: the product structure and the process maps. This would effectively make the recorded actions and lessons learnt visible in the engineer's working environment.

To date, the strategy developed in this chapter has not been completely tested. The author has essentially focused on the knowledge acquisition stage of the process. A "design review capture template" was therefore created based on the MCT described in chapter 4. Indeed, the feedback from the students who used the MCT encouraged the application of the same format for the capture of actions during meetings. This new template was trialled by the author, and subsequent improvements and guidelines for its usage were then established. The template fulfils most of the requirements outlined in the strategy, and is currently being tested in industry. Feedback on the performance of the template and comments on the associated meeting management guidelines will hopefully soon be made available by Airbus UK.

Finally, computer support for the action-oriented strategy has been investigated and a conceptual solution has been proposed in this chapter. The approach seeks to build a software based on the "design review capture template", but with added digital functionalities such as: hyperlinks, digital artefact annotation, automatic summarisation tables (for actions and lessons learnt). The proposal carefully avoids organizational barriers related to the integration of technology in the workplace, e.g. "the big brother" syndrome outlined in chapter 3 (§4.2). The main advantage of this computer-based prototype over its paper-based counterpart is its integration to the digital environment in which design engineers work. Indeed, most of the artefacts discussed during a design review are nowadays available in a digital format. The proposed technology would therefore integrate an "artefact viewer" which would enable the user to annotate and copy (as a picture) any element of the artefact under review and insert the result in the minutes of the meeting. Most of the functionalities envisaged are already available in various software solutions (not necessarily for meeting capture), which adds credit to the scenario presented. The "design review capture software" would also benefit from a novel hardware setting where handwritten comments from various participants could be integrated; further investigations need to be made in order to outline possible set-ups where handwriting recognition technologies can be employed (e.g. Tablet PC and Digital Pens).

CHAPTER 7

CONCLUSION AND FUTURE WORK

The study of engineering teams working in the context of aerospace design reviews reported in this thesis has led to a conceptual understanding of the review activities (chapter 3) and the development of three unique meeting analysis tools (chapter 4). Overall, the results generated by this set of tools, used to analyse the DTM case studies, have provided practical insights into the communication and information processes, and the knowledge loss that can occur during design reviews (chapter 5). From this comprehensive view on this collaborative event, the research then focused on current means used in the aerospace industry for the task of minute taking. A study of examples of design review minutes and a survey on their role in the design process fostered the elaboration of an action-oriented strategy to improve the content of these documents; as a general rule, company guidelines and policies should seek to implement or strengthen the role of actions in design reviews (chapter 6). Along with the action-oriented strategy, a set of guidelines, a capture template, and the conceptual requirements for the elaboration of a software to support the knowledge intensive capture of design review contents were proposed by the author.

This final chapter will draw conclusions from the discussion on how to record aerospace design reviews to capture the important knowledge elements for further reuse, and outline opportunities for future research based on the work reported in this thesis.

1. CONCLUSION AND ANSWERS TO THE RESEARCH QUESTIONS

Only a limited number of observational studies in engineering have focused on a clearly identifiable type of meeting. The DTM case studies, however, chose to use a very specific and widespread meeting event in the aerospace industry: design reviews. Although the design review process has been an important topic of research over the years, the study of the meeting activity itself has not drawn much attention in the field of engineering design research. Companies using a Stage-Gate approach to control their product development activities implement design reviews with similar guidelines, which clearly distinguish them from other meetings typically held in the workplace (Chapter 1, §1.2.4): they are guided by a number of formalised constraints, they follow a clear set of predefined objectives, they are a unique "information synchronization" point for all stakeholders involved in the development of a product, they are visible activities in business planning tools and documents across projects and companies, and they are at the heart of the collaborative decision making cycle inherent to any product development process.

From the literature reviewed and analysed in the first three chapters, design review meetings clearly stand out as fundamental collaborative events for engineering teams working on the development of a complex product. Formally acknowledged by companies and standards as cornerstones of the design control process, design reviews are a place where the various stakeholders in a project can meet face-to-face to: share information about the design and its associated processes, evaluate the design achievements, and take the necessary decisions to improve the management of the design (chapter 3, §2.2).

The research reported in this thesis has therefore been directed towards a naturalistic observation of engineering teams in a design review situation. A specific research methodology composed of three research cycles ("explore", "tune", and "interact"; see chapter 1, §2.2.2) was developed, and provided a flexible framework for:

- A transparent and reproducible qualitative research process
- The collection of qualitative data from different types of case studies (*in situ* or simulated setting, academic or industrial participants, etc.)
- The development and validation of various research tools focused on the analysis of verbal transactions during design reviews

Based on this successful research process, a number of contributions answering the overarching research question – *how is it possible to record design review meetings to* *capture the important knowledge elements for further reuse?* – were made. Key findings detailed in chapters 3, 5 and 6 include:

- A conceptual understanding of the activity under study (chapter 3)
- Critical aspects in terms of communication & information processes, and knowledge loss (chapter 5)
- The survey of current minute taking practices in the aerospace industry (chapter 6)
- An action-oriented strategy for the capture of design review contents (chapter 6)

To conclude the work reported in this thesis, a detailed summary of the findings and contributions has been clustered using the sub-set of 7 questions outlined in chapter 1 (§2.3). Hence, each one of the following sub-sections answers directly one of the underlying research questions that have motivated the work reported in this thesis.

1.1. What types of communication and information processes occur during meetings?

While chapter 2 focused more generally on communication and information processes observed in the literature for engineering teams, it also strongly highlighted which findings were applicable in the case of meetings or more specifically design reviews.

The communication processes which take place during design reviews are typically held in a synchronous manner and the essential communication channel – speech – is systematically augmented by a visual stimuli (3D models, sketches, documents, gestures, physical parts etc.). The event falls into the communication category of interface negotiation where engineers working on the same project are invited to share their opinions on predetermined issues. Participants are also required to report on their work as part of a formal problem handling situation. Spoken information shared during meetings is typically of an unstructured nature, but in the case of design reviews the process is usually structured by textual and pictorial information sources (prerequisites for the review to take place).

To further the understanding of meetings and design reviews in particular, two complementary models of a design meeting were built in chapter 3: an object-oriented model and a process-oriented model. These models use a set of concepts generated from a comparative study of the terminology used by engineering research teams which have worked on the topic of meeting analysis in the past.

The object-oriented model is a simple hierarchical classification of meeting elements, essential to observe and analyse meetings in an engineering context. The hierarchy is divided into two main branches: one branch groups the entities related to the structure of the meeting (elements on which the meeting needs to be built, e.g. participants, resources, etc.), while the other branch is composed of entities related to the content of the meeting (elements which help characterise the nature and content of the information transactions that take place, e.g. topic of conversation, input information, communication elements, etc.).

The process-oriented model uses an $IDEF_0$ approach to represent the various information processes which are expected to occur during a design review. This model shows how the activity of "reviewing the design achievements", core to design review meetings, can be decomposed in a sub-set of 3 interrelated activities:

- "Share information about the design"
- "Evaluate the design"
- "Manage the design"

Ultimately, this model shows how key knowledge elements, i.e. design rationale and lessons learnt, are transferred between the 3 main design review activities but are never truly related to any of the outputs of the design review process.

The two representation models of a meeting described above ultimately provide the necessary context and structure for the development of a number of different meeting analysis tools detailed in chapter 4.

1.2. How is it possible to analyse design discourse?

The single most important practical aspect for an efficient study of spoken discourse is the use of verbatim transcripts (chapter 3, §1.1). These enable the precise analysis of verbal transactions between participants based on a predetermined coding scheme. A unique Transcript Coding Scheme (TCS) was therefore developed for the purpose of the DTM case studies. This coding scheme was a result of the comparative study mentioned in the answer to question 1, and was adopted to produce measures according to a number of research criteria, namely: roles of the participants, intervention types, exchange roles, information types, artefact types, domains of competence involved, origin of the topics of discussion. The TCS tables, which include the transcript of the meeting and its coding, were at the basis of the development of two other analytical tools, the Meeting Capture

Template (MCT) and the Information Mapping Technique (IMT), which fulfil specific objectives not met by the TCS.

The MCT enables the user to code the meeting as it is happening, effectively bypassing the transcribing process imposed by the TCS. An MCT presents itself as a table where each entry (or line) corresponds to a new conversation topic. Each entry can then be coded directly by the user; the columns of the MCT relate to a coding criteria derived from the TCS. An MCT can be used to analyse a design meeting according to the following aspects: participant role, exchange roles, information types, and topics of discussions (with their associated actions). The MCT was successfully trialled and developed during the CAMAQ project case study.

Finally, the (IMT) was specifically developed to measure levels of knowledge loss from design reviews based on the comparison of two documents: the minutes and the transcript of the meeting. The IMT is therefore text-based and requires the user to single out specific information entities in the document under consideration. These information entities are the expression of key knowledge elements – rationale, decisions, lessons learnt, and actions – described in chapter 2 as essential to capture for both the project's and the company's memory. The information entities are then associated to a specific symbol according to their knowledge type and these are mapped out in a succession of network graphs which follow the topic thread in the document. The results from the IMT served to illustrate the levels of knowledge loss in minutes of meetings and fostered a number of empirical hypotheses to counter this problem.

1.3. What is a meeting? What characterises a design review and the transactions that take place there?

The two models of a design meeting, described in the answer to question 1.1, provide an in depth understanding of its constitutive elements and generic information processes. Based on this work, it was possible to outline a broad definition of a design meeting:

A design meeting is a set of communication processes which take place in a synchronous or asynchronous manner over issues linked to spontaneous or predetermined topics. A design meeting aims at achieving general agreement over design issues by spreading information between at least 2 participants with the support of specific artefacts.

Of course, this definition means that many collaborative situations can be considered as a meeting, but this is a reality imposed by "global" companies working in hi-tech environments (see chapter 3, section 4). Through the analysis of the results from the DTM case studies, Chapter 5 offers a more practical characterisation of design reviews based on the empirical data processed by the analytical tools developed for the purpose of this research. The following points below summarise and discuss the key observations based on the monitored design reviews:

- *The study of the communication structure* explains the failure of certain established design rationale capture techniques, such as IBIS, when applied to spoken discourse. Indeed, these techniques are focussed on "question and answer" sequences aiming at unveiling the rationale in the conversation. But in fact, in the meetings observed, the questions were rarely answered by a straightforward or direct answer.
- *The study of the underlying communication intent* in the conversations monitored suggests that the "sharing information about the design" activity in the process-oriented design review model proposed in chapter 3 (§2.2) is an important activity in the overall design review process; the DTM case studies show that 60-70% of the conversation time is related to "information sharing".
- *The study of decision making patterns* reveals that in the design reviews monitored the decision making process follows sequence patterns, which ultimately reflect a rational course of decision making with few conflicts of interest between participants (see chapter 5, §2.3).
- *The study of the level of structure of the information exchanged* during the Airbus UK case study indicates that 60-70% of the conversation topics were predetermined by the meeting agenda and the remaining topics of discussion are directly derived from these. Design reviews can therefore be considered as a structured type of meeting.
- *The study of the content of the information* shared between participants, in the case of the CAMAQ project, also showed how design issues were at the heart of most conversations throughout the 4 design reviews monitored, with a peak at PDR. Management issues were dealt with early in the project (peak at RR), while manufacturing issues were only the true concern of the participants at CDR (with a critical low point at CR).

1.4. What are the available means to capture information during meetings?

As suggested in the definition of a design meeting in the answer to question 3, new technologies in the workplace have expanded the notion of meeting from a face-to-face situation to a temporally and physically distributed situation. Meeting technologies have therefore been examined in chapter 3 (section 4) according to two roles they can undertake: "meeting facilitation" and "information capture". While meeting facilitation can be directed towards both the content and structure elements of a meeting, information capture tools and techniques, on the other hand, are exclusively designed for the efficient extraction of meeting content.

Meeting facilitation can be understood as helping the organization and execution of the event, or as supporting efficient communication during meeting activities. Meeting facilitation tools therefore correspond to two fields of expertise: Computer Supported Cooperative Work (CSCW) and Group Decision Support Systems (GDSS).

In the case of "information capture" tools, the review (chapter 3, §4.2) clearly highlights the dominance of text-based approaches for the final capture of meetings contents. In this field, new handwriting recognition technologies (e.g. Tablet PC, Digital Pens) offer interesting perspectives for the capture of informal notes during meetings. When it comes to the management of the information captured during meetings, regardless of the format, two distinct approaches can be outlined: the automated approach and the human-facilitated approach. The automated approach is highly dependent on the success of speech and semantic recognition technologies. These hi-tech solutions, however, stumble upon major technological barriers. The human-facilitated approach is therefore the preferred option for the time being, but these must also overcome a number of cultural barriers when capturing meeting content with video or audio technologies.

1.5. What are the important knowledge elements that are not currently captured during design reviews?

From the analysis of the literature related to KM and the specificities of design review activities (chapter 2), milestone meetings seem predisposed for substantial knowledge creation and critical decision making: participants typically update their information about the design, discuss the rationale leading to a collaborative plan of actions, and share past experiences. This observation has sparked interest in three key knowledge elements: rationale, decisions, and lessons learnt. These elements have therefore been singled out in this research for the efficient knowledge-oriented recording of information exchanges during design reviews.

The results from the knowledge loss study, detailed in chapter 5 (section 4), which was carried out using the IMT on the minutes and the transcript of the Airbus UK Requirement Review, showed that the minute taker seems more capable of recoding the associated rationale, lessons learnt, and decisions based on an explicit expression of the action to be taken. This observation has inspired the definition of an action-oriented strategy for an improved knowledge capture during minute taking described in chapter 6 (§3.1).

1.6. Can design reviews be managed more efficiently?

The study of the role of participants discussed in chapter 3 (§3.1) suggests that participants are the knowledge and information creating sources in a meeting, and are responsible for the explicit rationale and lessons learnt shared during a review. Overall, from a design review process perspective, the role of participants can be grouped in three distinctive parties: the chairperson and minute taker orchestrate the meeting, the reviewers evaluate the design achievements, and the project team members present and justify the proposed design. The efficient management of design reviews is therefore strongly related to an improved definition of tasks and responsibilities which need to be shared between the participants of a design review.

In chapter 6 (section 2), a practical solution to improve the management of design reviews is proposed based on the results of a survey carried out in the aerospace industry (chapter 6, section 2): meeting minutes must be "action driven" in order to be productive. Indeed, the results of the survey are unequivocal: engineers learn to take minutes by experience and only truly value the actions list, the practical side of traditional minute taking. This also resonates with the results of the study of design review minutes at Airbus UK (chapter 6, section 1) and with meeting management guidelines mentioned in chapter 3 (section 4).

An action-oriented strategy to improve the capture of key knowledge elements from design reviews was therefore elaborated by the author. This strategy can be described in 3 steps from the minute taker's perspective:

1. First, during the meeting, the minute taker should focus on keeping track of the actions with their associated rationale or lessons learnt. This knowledge acquisition phase of the strategy would see the minute taker turn decision points into actions

whenever possible, and at the end of the meeting sufficient time should be allowed so that each action can be reviewed in detail and agreed by all participants.

2. The closing stages of the meeting would effectively initiate the knowledge representation and encoding stages of the strategy; each action or lesson learnt would be detailed and tagged according to the type of information it contains (product or process). After the meeting, the minute taker would finalise the formal meeting minutes by seeking the approval of the authorities responsible for the design review.

3. Once all the action and lessons learnt forms are approved, these can be linked to one of the two engineering tools used to manage product and process information. Actions tagged as "product information" could be inserted in the product structure tree managed by PDM systems, while those tagged as "process information" could be included in process maps or managed by workflow management systems. These operations would complete the knowledge implementation and reuse stage of the action-oriented strategy.

1.7. How should the knowledge elements be made available to designers for reuse?

The review of literature concerning KM (chapter 2, section 4), has highlighted certain failures of current KM approaches deployed in industry: for example knowledge based systems are often poorly integrated to engineering systems, and engineers are not provided with an adequate framework to implement knowledge-oriented practices in their activities. The work reported in this thesis proposes a distinctive approach to make the knowledge elements captured in the action-oriented strategy available to designers for further reuse (chapter 6). Indeed, the tagging process of the action-oriented strategy effectively aims at implementing the knowledge captured from design reviews in existing engineering or knowledge management tools.

The idea of tagging the captured information according to its type (product or process) takes its roots from current developments in design rationale representation systems presented in chapter 2 (§4.3.1). These systems are either feature-oriented or process-oriented. Moreover, the study of the information exchanged during the design reviews of the CAMAQ project has provided a unique illustration of the shift in balance between process and product information that occurs during the evolution of a design project (chapter 5, §3.3.2). The results from this research support claims made by other researchers on the shift between process knowledge and product knowledge across the life of a project.

Nevertheless, the results from the DTM case studies show that the balance between product and process information remains within a 40%-60% bracket. This trend means that, overall, process and product information are shared in large amounts across the life of a project, and systems aiming at capturing this design information should focus on a hybrid approach (feature-oriented/process-oriented).

Although design rationale representation systems offer interesting perspectives for knowledge reuse, these tools are still widely regarded as experimental prototypes. Hence, the proposal made in this thesis is to directly link the captured knowledge to existing engineering systems.

2. FUTURE WORK: CHALLENGING ENGINEERING AMNESIA WITH KNOWLEDGE-ORIENTED PRACTICES

The work reported in this thesis aimed at increasing the level of understanding of a particular aspect of design activity: the characteristics of design transactions communicated verbally between participants in a design review. This basic understanding was then used to propose a knowledge-oriented practice for engineers to improve the capture and reuse of the contents of design reviews. However, a number of issues raised by this dissertation remain and the author hopes that these will be addressed in future research.

The remaining research issues have been grouped into two distinctive categories. In a first instance, issues directly related to the work on design reviews will be outlined. Then a number of research issues directed towards the general implementation of Knowledge-Oriented Practices for Engineers will be proposed.

2.1. Future research opportunities based on the work discussed in this thesis

In chapter 6, a "design review capture template" was described and illustrated by its two latest versions. These were trialled at École Polytechnique and its latest version was then passed on to the KM team at Airbus UK. This template will therefore be subject to further modifications in order to comply with the company's specific documentation formatting and archiving requirements. These future developments concerning the capture templates (for actions and lessons learnt) are already part of an ongoing research process, but a number of issues raised in this thesis would also warrant further investigation:

- *A robust ontology to describe design meetings* could be built based on the meeting models presented in chapter 3. This could then be used by knowledge-based applications in order to efficiently organise the information generated by any type of design meeting.

- *An automatization of the 3 meeting analysis tools*, presented in chapter 4, should be sought; this would ultimately contribute to an automatic approach for information capture of meeting contents. This thesis has described the necessary processes followed to deploy these paper-based tools, and these descriptions could be used to generate algorithms which would help automate certain steps in the processes.

- The DTM case studies have helped to illustrate the use of the meeting analysis tools, and *more case studies could now be sought to deepen the characterisation of other specific types of meetings* . More data would effectively mean a more precise understanding of the underlying mechanisms observed (e.g. decision making patterns), and could also benefit the elaboration of precise meeting management guidelines based on examples in the engineering domain.

- *A specific investigation into the types of information used by engineers* during different types of design reviews. This issue would effectively relate to the findings reported in this research on "product versus process information" (chapter 5, §3.3.2). This type of study would undoubtedly benefit research and development of design rationale capture systems.

- *A specific investigation into the role of artefacts during meetings.* One of the interesting and slightly surprising findings from the research is the importance of the role of artefacts. The results from the TCS particularly have shown that artefacts clearly structure and focus both the communication intent and the type of information exchanged between participants of a design meeting. More needs to be done in order to understand this influence. This type of study would enable a more efficient use of design artefacts during meetings and also help information capture systems integrate the information generated from the use of these artefacts.

- *Expand the Information Mapping Technique* to other topics of research in the domain of information management. The IMT has been used in this research to measure organisational knowledge loss, but information mapping is thought to have much more to offer in the field of design research. A new form of design rationale representation could be developed and a further study of this technique could give practical insights into alternative information archiving strategies.

- *Continue the development of the "design review capture software".* Chapter 6 has outlined the conceptual requirements for the design and development of a meeting capture software. More needs to be done to evaluate the technological feasibility of the proposed functional requirements of the software. The integration of the captured actions and lessons learnt forms to existing engineering information management systems (e.g. PDM, PLM, workflow management, etc.) should also be investigated.
- *Investigate and test new hardware settings for design meetings.* New technologies such as handwriting recognition software are sufficiently mature to offer interesting perspectives for the efficient capture of meeting contents. Tablet PC and Digital Pen technologies for example could add richness to the content of the minutes by adding personal notes taken by the participants to the final record in the form of comments. Research should seek to evaluate hardware settings which include such technologies and how these can be efficiently managed by the participants. Initial work in this area has been started by a research colleague at the University of Bath.

2.2. Research in Knowledge-Oriented Practices for Engineers

This thesis has discussed issues related to a specific engineering activity – design reviews – with the underlying objective of proposing a knowledge-oriented approach to minute taking and design review management. The research methodology developed for this specific purpose could be expanded to other engineering activities, with the general aim of developing Knowledge-Oriented Practices for Engineers (KOPE) working in different stages of the product development process. From the research experience gained over the past four years in the field of mechanical engineering and KM, the author believes that KOPE could become a major research theme for the integration of "knowledge awareness" in engineering practices.

The following KOPE research framework lists a number of potential research areas which could lead to practical solutions for the enhancement of a company's intellectual capital:

- *Understand and differentiate the specific knowledge requirements of each engineering domain involved in the life cycle of a product.* KM research has too often assumed that knowledge processes in engineering can be generalised, when in fact, each domain might have very specific knowledge generation processes. For example, design knowledge and manufacturing knowledge are probably not acquired by the same process.

- *Investigate the knowledge transfer processes which exist between the various engineering activities.* This will help to pin point both successful practices and current pitfalls in typical knowledge flows observed in a company. The flow of information between engineering design and manufacturing is still a critical aspect difficult to manage for most companies.
- *Seek proper integration of knowledge-based applications and engineering systems.* Engineering tools are gradually succeeding to offer companies PLM systems which manage engineering data across the life-cycle of a product. It seems crucial for researchers to analyse these new solutions in order to propose integrated knowledge-oriented enhancements and offer a Product Life-cycle Knowledge Management system (PLKM) for example. It would also be important to associate information archiving strategies with the various KOPE developed to avoid information overload for the engineer and multiplication of data bases for a company.

The prospective areas of investigation of the KOPE thematic are still very much in an "incubation" state and will most definitely be subject to change. Nevertheless, this set of proposals demonstrates how, from a specific observational study of designers, the author has gradually widen his scope of interest to the entire engineering activities involved in the development of a product.

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APPENDIX A

FULL TRANSCRIPT AND CODING OF THE AIRBUS UK REQUIREMENT REVIEW

This appendix presents the full transcript and coding of the Airbus UK Requirement Review recorded and observed by the author at Filton (Bristol, UK) in December 2003.

Reminder of the coding conventions for the TCS:

Name of column in TCS	**Coding criterion**	**Coding elements (with shorthand conventions used in TCS)**
1	Intervention type	Statement (S), question (Q), answer (A), or feeling/emotion (F)
Exch. role	Exchange role	Informing (INF), exploring (EXP), resolving problems (RES), managing (MAN), evaluating (EVA), debating (DEB), digressing (DIG), clarifying (CLA), or decision making (DEC)
Info type	Information type	Product (Prod.), process (Proc.), resources (Res.), or external factors (Ext.)
Artefact type	Artefact type	Office (O), Drawing (D), Activity management (AM), Information management (IM), Calculation (Ca), Communication (Co), Component (C), or Testing (T)
Topic origin	Origin of the discussed topic	Predetermined (P), derived (D), or unexpected (U)

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	Review of the equipment specification, changes only …	00:07:28	S	[INF]	Ext	RR_equipment_ specification document	AM	Aircraft configuration & architecture	information on dry bays for supplier	P
AW	Yes, so if everybody has visibility of it … so the two main changes are on page two slash four, dash four even relating to the dry base, we've added a section underneath the cell tank and architecture paragraph, to include some weasel word about dry bays …	00:07:56	S							
GW	Why do you say weasel word?	00:07:57	Q							
AW	It's because … alright weasel is a bad choice of word (laughs), ok to try and define dry bay … I guess everybody's read this before or am I being hopeful	00:08:18	A							
GW	Yes I'd like to go through them one at a time, the first item then the additional set of tank approximately 2900 litres why has that changed?	00:08:24	Q	[EXP]	Prod					
AW	It hasn't changed, oh ok no there's an error, it hasn't changed … it must be related to the dry bays above	00:08:34	A							
GW	So you're adding a statement: left and right wings have symmetrical dry bays fitted; 2 dry bays in each wing defined as follows. So it's background data … (GW reading the doc in low tone voice) …that's the key requirement so you've them background about the dry bay definition and then you're saying you want an option where you don't want dry bays	00:09:04	S							
AW	That was a specific question from *Supplier* was to know whether left and right tanks where symmetrical, that's why we included that statement and a … they've got diagrams, drawings of the dry bays but we thought for completeness it's best if we put it in words to	00:09:18	S							
GW	Ok, then you put in: "further information on dry bays is available in that reference document", so it leads on to	00:09:29	S							
AW	That's currently updated …	00:09:31	S							
GW	Ok so that's the dry bay element	00:09:35	S							
BD	One comment that I made is that there are numbers quoted for the tank with dry bays, we ought to quote it for … without	00:09:45	S	[DEC]	Proc					
GW	For fuel quantities?	00:09:47	Q							
BD	Yeah approximate quantities … otherwise it seems inappropriate to have just one set	00:09:53	A							
GW	Or at least identify what the quantity of a dry bay is … so it's one way or the other	00:10:00	S							
X	Yeah …	00:10:01	F							
GW	… So that's an action please then	00:10:12	S							
JW	Could we also check, AW, that with the cost production team and program that they are still proposing that when they delete dry bays, they delete them both because I've heard that they may only delete one	00:10:24	S	[EXP]	Prod			Aircraft configuration & architecture	A/C with no dry bays, 1 dry bay?	D
AW	Yeah that was due to a study of the rotor and they concluded that they could only delete one and the study was to see if they could delete the second one … I think subject to	00:10:36	S							
JW	I think you need to clarify that	00:10:37	S							
GW	The requirement is for deletion of two dry bays, that's an aircraft with no dry bays … that's a requirement being set, that's the aircraft level requirement	00:10:47	S							
BD	Should we at this level cope with the other possible options	00:10:50	Q							
JW	Which is one installed	00:10:53	S							
BD	And do we know it's left or right or should we cover both separately, I mean from a software point of view it's probably easier to do it once and cover all those options so that if that eventually happens later we've covered them, rather than go back and change the software later	00:11:09	Q							
PW	We've already catered for this the loss of one dry bay… don't we and … the existing one	00:11:16	S							
BD	No I was just wondering, in the configuration we spell out here we ought to give all four combinations	00:11:25	Q							
[…]	[…]=[arrival of PFS]	00:11:55								
GW	It just concerns me now because you're question the basic requirement for the whole job	00:11:59	S							
BD	This is the best place to queer it rather than in 3 years time	00:12:03	S							
NH	What do we do with 320? Do we provide 2 separate ones or do we delete them both?	00:12:11	Q							
[…]	[…]=[background noise, sitting reconfiguration]	00:13:57								
GW	Since the dry bay deletion activity in itself, the actual dry bay deletion activity is an ongoing development, it's going to be difficult for us to keep up with what they eventually do decide what they want to do. We have to put a stake in the ground, the stake in the ground we put in was is deletion of the dry bays	00:14:17	S							
JW	I still think it is time to go back to the people running the dry bay project and say what is their configuration they are going to do and … they might be one gone and	00:14:30	S							
MD	There is no rerun of the dry bay	00:14:33	S							
JW	There is	00:14:34	S							
MD	Because when we looked at it earlier on it was … nobody was looking at it	00:14:37	S							
JW	There is, it's IL …	00:14:40	S							
GW	Yeah and they could well end up with a solution which is reducing the size of the dry bay, which is another option … they're a little bit in the air at the moment, I can fully accept that there is a question mark there and as we are reviewing the requirements and there is a question mark over that requirement then there should be an action placed for somebody to validate that requirement with the dry bay team	00:15:06	S							
NH	I suggest it's JW that did it as the co-author of the top level requirements document, you could just confirm what the top level requirement is for dry bay deletion	00:15:15	S	[DEC]	Ext					
JW	Yeah	00:15:16	F							
[…]	[…]=[jokes]	00:15:50								
JW	And the answer may be that they are unclear …we'll phone up the top level requirements	00:16:01	S							
GW	We'll have to, we have to understand that the basic driver for this particular project is the fuel leak detection, the dry bay deletion part is taking an opportunity while the software is being opened, so if they are unclear we are not going to stop this project, we'll go with our most confident solution	00:16:25	S							
[…]	[…]=[can't understand audio and silence]	00:16:58								

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
AW	Ok, fuel leak detection, first point we kind of stole this one from 320 with a few additions, the input parameters is a new section, I thought we'd add that in to clarify to *Supplier*	00:17:18	S	[CLA]	Prod	RR_equipment_spec page 2-10	AM/Ca	Systems design	fuel leak detection based on A320	P
GW	So what you're implying here is that ... the same solution as we've used on A320	00:17:23	Q							
AW	Mostly yes, there's a few differences, so I'll go for it: the difference is ... we've tidied up a couple of ... the definitions of the variables, so we've included a 'if it's true do this but if it's false then do something else' which was implied before but never really stated and the main change we've done is that we've brought the fuel leak threshold value which is on page 2-11 brought the calculation in line with the corporate jet, so what we've got is a slightly different solution, so we've actually produced tables 3 and 4 which give two functions that you input in the threshold calculation previously it was done by looking at tables ... that was really all the changes we've done to this one	00:18:29	S							
GW	Is this definition, these requirements for fuel leak detection function, are being validated within the engineering domain?	00:18:45	Q	[CLA]	Proc					
AW	Well, kind of, they worked on... we used them on 320 and also *Supplier* produced a definition of the algorithm they were going to send us to define how they were going to program this function and we've gone through that and comments and validated the *Supplier* 's interpretation against the requirements	00:19:17	S							
GW	Ok I'm looking ahead here, I'm thinking design issues here, I'm looking at this spec is going to be signed up by PS and PFS and they are going to ask some sort of justification of what we've got here, which is quite complex is correct so ultimately you're going to have to validate that it is correct to the signatories ... just something that you have to bear in mind for the near future	00:19:43	S	[EXP]	Proc					
GW	So those really are the only requirements that you put in the spec then?	00:19:47	Q	[CLA]	Prod					
AW	Exactly ... there's a few minor changes to other parts but they're really the typos and the only other one is the change to the minus 2000 feet but I haven't got a lot to say about that ...	00:20:07	A							
GW	So you've added in the requirement there that the equipment should operate down to minus 2000 feet	00:20:11	Q							
AW	Yeah	00:20:12	A							
GW	Good	00:20:13	F							
GW	In this spec for verification work by the supplier ...	00:20:26	Q	[EXP]	Proc			Certification & testing	verification and validation process for the supplier	D
AW	I haven't changed anything so that it would be the same as previous, but as I don't know what the previous was ...	00:20:29	A							
GW	What I'm thinking is lessons learnt, we've had problems with supplier's equipment of late and it comes to pass that the amount of verification that they've done was inadequate to identify that the equipment actually had problems and the opportunity should be taken now to formally identify it to the supplier that we want a more robust V and V activity. How robust, how would you define that, I don't know. I think we should be requiring them to do more than what they've done in the past	00:21:08	S							
RA	Are you thinking software, hardware ...	00:21:10	Q							
GW	Yes	00:21:11	A							
RA	Integration? ...	00:21:14	Q							
GW	I'm not thinking of any specific element, I'm thinking across the board to be honest	00:21:19	S							
TT	GW?, I'd like to point out the equipment specs written against the DO178A and I think we are moving towards doing this to 178B that would be and so	00:21:36	S	[CLA]	Ext			Project management & business	specifications of the design in accordance with formal guidelines and regulations: ABD0100 and DO178B	P
BD	Only true for the changes	00:21:38	S							
TT	... Sorry?	00:21:39	Q							
BD	That's probably only true for the changes	00:21:41	Q							
TT	Yes, that's only true for the changes but the life cycle is significantly different and a lot of the sections to the computer software will change on the basis of that	00:22:01	S							
GW	I'd certainly need to change to identify that you're using DO178B for the change parts of the software	00:22:08	S							
RA	And ABD0100 instead of ABD0015	00:22:11	S							
GW	Yeah, we haven't done that at the moment though	00:22:14	S							
TT	It's included ... that's included in that ...	00:22:20	S							
RA	But there are details that haven't been changed ...	00:22:28	S							
JW	2.12 is based on the old philosophy	00:22:34	S							
TT	2.12 is in?	00:22:36	Q							
JW	2.12 that's two point twelve	00:22:40	A							
PW	Page 2-38	00:22:42	A							
TT	So if you look at this, although it mentions DO-178A or DO-178B depending on the software module, it's ... actually all the documentation written against ABD0015 and now we're using 100 that's 2.4 or DO-178B level, so if we're going with D0-178B we're going to have to revisit this whole section	00:23:23	S	[RES]	Ext					
JW	I recon it's only a replace	00:23:25	S							
TT	I hope...	00:23:26	F							
MD	Because if you replace ABD 0015 by ABD 0100 and DO-178A by DO-178B it still fits, there's the odd paragraph number that needs a change but it's not a big change. There is this open issue GW about aircraft whether certification basis was A and how do we go towards a B standard under those circumstances do we put *either no equipment or modified* , now discussions that we've had with the authorities indicate that we go to B, but what we can't ... we can find on certain aircrafts where there's a *cree raised* or something that covers it. On this particular aircraft we can't so the plan at the moment is to speak to PM to see what the intention of the authorities are to cover the others, the odds and sods and this is one of them and we're meeting with them tomorrow ... I think in the mean time we need to, we have to assume that there will have to be a modification here, I think that's the right way to assume and that will help with your V&V issue which I totally agree with from the software point of view right up to the software-hardware integration. If we need to think about it in some other area, then we need to deal separately with	00:25:06	S							
GW	In that case, make sure I'm clear of what you're telling me here, we previously developed the software to level A, new software should be developed not to A ... my terminology here, sorry DO-178 issue A and we now need to go to future software, we are supposed to be using DO-178B, where we are modifying the software, the question is: do you use A or B? From the project office point of view we have a definition that says that if it's a ... only a modification to an existing software then it's open to debate, and I think what you're saying is we are moving towards saying that the modified software the part of the software which is changing should be changed according to B, but we don't have to validate the whole software to B?	00:25:56	Q	[CLA]	Proc					
MD	No	00:25:57	A							
GW	That would be a very good solution	00:25:59	S							
TT	Is there some regression testing that covers the ...	00:26:02	Q							
MD	When you come up into the integration level, then of course you have to consider B instead of A, so at the module level, at the lower level then it's only change components against B and when you go to the integration you're talking B instead of A	00:26:22	S							
GW	What's that going to imply for the program?	00:26:25	Q	[EXP]	Proc			Project management & business	Implications of the choice of guidelines on the supplier's development process	D
MD	There are a couple of extra activities or a couple of extra things that they need to account, most of the suppliers that we have spoken to today have already taken B into account as far as their development methodology is concerned so it's not a problem *list of suppliers* as far as this one is concerned this is *Supplier* ?	00:26:51	S							
GW	*Supplier* , yes	00:26:52	A							
MD	When I did a part 6 on *Supplier* , they moved their procedures to standard B, so in theory I don't think there's a problem but obviously when TT does his first review with them that will obviously be taken into account	00:27:13	S							
TT	And these have been applied to *Supplier2* ?	00:27:17	Q							
MD	Once again we know *Supplier2* have gone to B anyway but they are procedures	00:27:23	S							
GW	Obviously B gives a better software	00:27:25	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
AW	*Supplier* are aware of our position?	00:27:28	Q	[DEC]	Proc	RR_equipment_spec page 2-10 (followed)	AM/Ca (followed)			
GW	They are	00:27:29	A							
AW	Well … we've said that from day one that we wanted B anyway	00:27:33	S							
GW	So all the plans should have already been taken into account	00:27:37	Q							
MD	I think, subject to our discussion tomorrow evening, tomorrow evening meeting, I think we need to assume that this section will have to be updated	00:27:51	S							
AW	Sure	00:27:52	F							
AW	Ok, I've taken that as an action	00:27:55	S							
PW	What you've just said to us isn't definitive, what areas in that do you think might be subject to change with the discussion? … that seems to be quite a clear a plan that we've already worked to	00:28:17	Q	[DEB]	Proc			Project management & business	issue of requirements on the equipment supplier will be addressed	D
MD	… The difficulty we have is that they changed their personnel in *X*, the software specialist, that person who was responsible was in the process of insuring that the philosophy was applied throughout all developments and it never completed, the task never completed there was going to be a TN and organise and it didn't happen. So at the moment formally it's only covered on some aircrafts, 340 for example, so to my knowledge it's not covered on this particular aircraft so it may be from discussion that they agree that it's not necessary on this aircraft, now that /we can still/	00:29:02	S							
GW	/yeah but/ we have arguments to stick with A	00:29:07	S							
MD	We have … but it would then not satisfy your objective which I fully support … making sure that we get a decent product, and personally I would suggest that we go this way what ever	00:29:26	S							
GW	And that needs to be reflected in the spec then?	00:29:29	Q							
MD	yeah	00:29:30	A							
PFS	The certification and qualification section already says that, it does state here that/	00:29:35	S	[RES]	Proc					
MD	/Absolutely right it's just the details that have gone a bit wacky	00:29:39	S							
GW	Yeah but how many times have we suffered because we don't have the details	00:29:42	S							
PFS	You're right, you're right but we've got it, we've picked it up basically	00:29:45	S							
GW	Ok, that was the side of the software element of the MB, going back to my particular concern the wider level of the MB are we going to enter these spec requirements there?	00:30:00	Q	[CLA]	Ext			Certification & testing	review V&V plan for suppliers	D
AW	To be honest I hadn't planed to	00:30:02	A							
GW	Like being specific and saying that their tests, their qualification testing should be done in flight load for example? Or being done on the ground? Little lessons learnt like that	00:30:15	S							
EH	What hardware standard have we brought up?	00:30:18	Q	[EXP]	Proc					
AW	What for the FQIC? It's the existing one but I can't remember what/	00:30:23	A							
BD	/We haven't actually called for a hardware standard/	00:30:26	S							
MD	But we've got the new hardware DO in place	00:30:29	S							
PW	But there is no hardware change …	00:30:36	S							
MD	That's true	00:30:40	S							
GW	No but we want to make sure that the hardware integrates properly with the software and all works nicely together	00:30:46	S	[RES]	Ext					
TT	I think personally if we move into writing DO-178B in our requirements for the software we ought to put a statement in here regarding the hardware saying if the hardware changes we do it to the later standard and it's in there forever …	00:31:03	S							
GW	That won't get us around this particular event where the software and the hardware isn't changing. I do think that/	00:31:09	S							
TT	/I mean, it may be that there is something that we don't know about today that in two months time forces a hardware change because of memory issues or something but if we put it in the spec now we are covered for it	00:31:20	S							
GW	Well, I think we should consider doing that	00:31:23	S							
GW	… I'll still reiterate my concern is that you need to revisit what specification formerly requires a supplier to do in terms of verification activities with a view to making sure that they are formerly required to do a level of rigor, apply a level of rigor that is consistent with what we're going to do on our rigs … depending on what your verification plan says of course but we'll come on to that	00:31:50	S	[EXP]	Ext					
TT	Is that done by us requesting a verification plan from them? …	00:31:55	Q							
PW	… Yes, the requirements are actually defined in ADB0100, so you get the verification plan from them	00:32:08	A							
TT	Well what I'm saying is: is that request already in ABD0100 or do we have to reiterate it…	00:32:16	Q							
JW	There's just a commercial element in that though, if … we reject their maturity plan for whatever reason and it doesn't meet our requirements and *they haven't taken that account in their quote they can slack a claim on us and we end up in a pay debt*	00:32:32	S							
GW	I think it's hidden under my concern /is that/	00:32:36	S							
JW	/We don't want/ to pay/	00:32:37	S							
GW	/If you're half way down the program, you've dealt with your contracts, recently started to talk to *Supplier* about hundreds of hours of maturity testing on such a rig and they come back to you and say: yep fine here's the extra bill.	00:32:50	S							
JW	Get it all in up front	00:32:52	S							
X	Yeah	00:32:53	F	[DEC]	Ext					
GW	Can you take an action to review your V&V requirements please …	00:33:03	S							
PB	There is a verification matrix in your management plan	00:33:06	S	[CLA]	Proc					
AW	Yeah, hmm/	00:33:07	S							
PB	Could it be added into that?	00:33:09	Q							
AW	It could, I did that mostly from my point of view, from our point of view I just added a very basic table/	00:33:19	A							
GW	/Please mind that what I'm talking about is something that goes into the specification down to the supplier, the management plan is an internal document, ok	00:33:30	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	I've also got here the aircraft level requirements, can I just skim through them just to make sure that we are happy that there is nothing else that needs to go into the stack, ok?, apologies to anyone that hasn't got a copy just bear with me. First section is just general introduction background, second section is the source documents, then we're into performance.	00:33:56	S	[INF]	Prod	RR_equipment_spec page 2-10 (followed)	AM/Ca (followed)	Aircraft configuration & architecture	new A/C level FQIC requirements	P
GW	Right: a new standard of FQIC shall give functionality to fuel leak detection and dry bay deletion, we're ok there, we've got those covered. The introduction of this additional functionality shall not increase the risk that aircraft safety objectives are affected elsewhere, that *won't impact* the spec. The FQIC function shall be designed to minimise the risk of spurious warnings, taken out on board throughout the design and development activity but not to be specified in the spec. Performance in the fuel systems shall not be degraded by the additional functionality. In order to provide/	00:34:35	S							
PW	That's a small 'd' I guess	00:34:37	Q	[CLA]	Proc					
GW	It is a small 'd', yes	00:34:39	A							
PW	Because degraded in *FQI* means something	00:34:41	S							
GW	Degraded mode, yes, I have come across that	00:34:45	S							
GW	In order to provide consistency with the A318 and to prepare for future A321 requirements the environmental requirements for operation of the computer shall be extended from minus 1000 feet to minus 2000 feet and we've got that in there.	00:34:57	Q	[CLA]	Prod					
AW	Yep	00:34:58	A							
GW	Existing problem reports that can be resolved as part of this development shall be included subject to agreement by BSOUX and BSMU and/	00:35:08	S							
AW	I attempted to do that but it's still in working progress	00:35:12	S							
GW	Ok, are there specific requirements that need to go in the specification for any of those problem reports or are they correcting problems in the detail design?	00:35:21	Q							
AW	Yeah, they are detail design issues	00:35:24	A							
PW	We have had a review to review the existing problem reports, I came up with a short list of ones to be addressed or to be considered for adressing, so it has gone through a formal procedure	00:35:40	S	[CLA]	Proc					
GW	The requirement is to identify what problems we want to fit in and at the moment you're saying that none of those problem reports would necessitate an additional requirement in the spec	00:35:50	Q							
PW	Exactly	00:35:51	A							
TT	Again it asks the question of how do we formally ask *Supplier* to fix those problems?	00:35:57	Q	[EXP]	Proc					
GW	… it all depends on what those problems are: if it's a deficiency with their original design	00:36:09	S							
TT	There are a number of those deficiencies we should probably take a subset of those and say please fix these and with that/	00:36:15	S							
GW	It would be done through a side meeting I suppose, it would have to be supported by some sort of commercial agreement to find out how we are going to pay to support them	00:36:28	S							
GW	… Our time doesn't come cheap, we are a business let's not forget …	00:36:39	S							
GW	Certification: a certification plans required and you've drafted that, certification basis for this task is currently JAR25 change 11 and no crees have been identified	00:36:55	S	[CLA]	Ext			Certification & testing	JAR25 issue 7	P
BD	And what about the work we've done on issue seven? Is that a different problem?	00:37:00	Q							
GW	Oh issue 7 is the joint certification basis it's the document that says that we are going to comply with change in there	00:37:07	S							
BD	Same thing then	00:37:09	Q							
GW	Yeah	00:37:10	A							
BD	Just doubles the level of confusion!	00:37:11	S							
GW	Safety and reliability: a safety assessment is required, we can say that's an Airbus document and there will be inputs to that from the supplier from the FMES which is standard requirements in the spec. Reliability requirements are unchanged	00:37:28	S	[CLA]	Proc			Manufacturing & procurement	safety and reliability issues	P
AW	Yeah I haven't changed them	00:37:30	S							
GW	… The reliability shall not be degraded ok so we are not changing the targets and they should meet those targets. Any additional maintenance inspection requirements must be defined minimised and justified, so that's just protecting ourselves. The direct maintenance cost targets for the new equipment at TBD, have we specified any DMC costs?	00:37:55	Q							
GW	… I take that's a no then!	00:38:03	A							
GW	… From a project point of view	00:38:07	S							
JW	No one has placed in a requirement to change it have they?	00:38:10	Q	[CLA]	Proc					
GW	Change it? What is 'it'?	00:38:14	Q							
JW	Maintainability	00:38:15	A							
GW	I don't think it was defined in the original spec with this/	00:38:18	S							
PW	/ maintainability is in section three, point four page 3-6	00:38:25	S							
GW	Could you check with the supportability team/	00:38:28	S	[DEC]	Proc					
AW	/ Yeah/	00:38:28	A							
GW	/to make sure there is no DMC that we should be identifying	00:38:31	S							
JW	What's a DMC?	00:38:32	Q	[INF]	Proc					
AW	/Data Maintenance Costs/	00:38:34	A							
GW	/Data Maintenance Costs/ I think you'll be talking to CK …	00:38:54	S							
GW	This one solution shall comply with the Airbus product handbook which is the replacement to the Airbus design handbook that we used to use.	00:39:00	S	[CLA]	Ext					
GW	The equipment development shall comply with Airbus, note that number, it's compliance with DO-178A versus DO-178B and DO-160B versus DO-160C. This Airbus note may be superseded by a final issue of certification review items because we know there is a Cree in preparation, Cree SE20 to do with the applicability of the new software …	00:39:35	S							
GW	The equipment is to be developed using ABD07 and to use the principles and guidelines of ABD200 where practical there is no requirement to use ABD200 on this job because there is only a minor change to a piece of equipment that was already developed. To ensure consistency with the latest requirements for equipment identification already applied to A318 and A320, the identification markings of a new standard of FQIC shall be in accordance to ABD100.2.9, is that in the spec/	00:40:14	Q							
AW	/Sorry that was 2.9 … yes it is, that includes the … sorry which one was that, about the identification and evolution of standards?	00:40:22	Q							
GW	Yeah	00:40:23	A							
AW	Yes they are all in there …	00:40:27	A							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	In order to ensure consistency with latest requirements for equipment configuration management, we should refer to 100.2.9 as well so that's in there. In order to ensure consistency with latest requirements for equipment component obsolescence, we should require compliance with ABD100.1.14	00:40:51	S	[EXP]	Ext	RR_equipment_spec page 2-10 (followed)	AM/Ca (followed)			
AW	I'll just check that then, what number?	00:40:53	Q							
NH	It's on page 6, 7-2…	00:41:03	A							
AW	ABD 1.14 … yeah that's there	00:41:09	A							
PW	The only question is: are they referenced in the text?	00:41:12	Q							
AW	Hmm, yeah they should be … yep, opposite obsolescence management: the management of equipment obsolescence shall be in accordance with ABD 0100 1.14 …	00:41:31	A							
GW	Does the current standard of equipment have a bar code on it?	00:41:35	Q	[EXP]	Prod			Manufacturing & procurement	equipment code bar	D
AW	No, well no, there wasn't a requirement to put a bar code on it, so it has not/	00:41:41	A							
GW	I know we've never placed a requirement for bar codes but I understand there has been some requirement placed through procurement …	00:41:50	S							
AW	I don't know if they have or not to be honest	00:41:53	S							
GW	I looked into *Supplier3* 's computer this morning and it has a very nice bar code on it,	00:41:58	S							
AW	yeah	00:41:59	F							
JW	Supplier3 chose to put that in have /they?/	00:42:00	Q							
GW	/They've/ already taken bar codes on board	00:42:04	S							
AW	But that was ABD 0100, wasn't it? *Supplier3* 's one? … it would have had that requirement from the start	00:42:15	Q							
GW	Ok, just a side issue that sprung to mind. Hmm, then there's our requirements on the team to have design views and to work to ensure that we get a mature product during service, I'm sure you've studied. Specific facts should be provided on verifying that the solution has been implemented correctly and is mature; it keeps coming through that point, doesn't it? All A321 Aircraft configurations must be considered, so we are talking basic A321 and up to two ACT's … Retrofitability: the new equipment will be one way interchangeable on condition, so it doesn't impact on the spec.	00:42:57	S	[CLA]	Proc			Systems design	retrofitability of the new equipment	D
RA	One way?	00:42:59	Q							
GW	Yeah, it's the old issue, you can't say it's two way because of the fuel leak detection function, so it's one way unless you don't have fuel leak detection in which case it's two way, it doesn't affect the spec. An SP solution is required for all later A321 variants in service including the VSP as appropriate, so that's the GCP2000 and that doesn't require a change to your spec at all…	00:43:34	S							
GW	Right, all interfaces associated with the new functionality shall be identified and the performance verified. The work shall be completed under the integrated fuel leak detection task …product support: there's no product support identified. Existing manufacture of the equipment shall … manufacturer of the equipment shall remain unchanged, i.e. We are not changing the supplier. The change of manufacture from old to new FQIC shall only occur when agreed by various parties at Airbus.	00:44:05	S	[CLA]	Proc			Manufacturing & procurement	change of part number	P
AW	Is that something the commercial will lay down or is that/	00:44:08	Q							
KM	Something we'll lay down	00:44:10	S							
AW	As in 'you' or as in 'us'?	00:44:13	Q							
KM	As in 'our program'	00:44:15	A							
AW	Right.	00:44:16	F							
GW	How will it manifest itself in the requirement on *Supplier* ?	00:44:20	Q							
KM	Effectively we will raise our MOD and we will set up (…) that will then fall through our procurement channel and they will change the part number and the demand will change on *Supplier*	00:44:36	S							
GW	Well, that won't be adequate, that merely gives the supplier the opportunity to say right we are going to stop building at this point and start building then. The issue is: let's not reduce their capability to build the current standard … until we are happy it's been fully verified.	00:45:00	S							
JW	*(…)* it will have to be part of a commercial agreement	00:45:20	S	[DEC]	Proc					
GW	Ok, will you ensure that it's part of the commercial agreement?	00:45:24	Q							
KM	Ok	00:45:25	A							
KM	I'm sure the commercial agreement won't be as far to the right as engineering would like it to be …but then it's not a date is it?	00:45:39	Q							
GW	I think the project team are wholly on board with your position and we'll endeavour to ensure that business is protected, won't we JW?	00:45:47	Q							
JW	yes	00:45:48	A							
GW	Project management we are going to use the CPD process, which is good. This task must encompass all associated business and activities, any additional opportunities to enhance the product's performance or reduce the cost shall be presented to project team for consideration and programme, at the start of the programme sorry! Before Airbus is committed to the change, ok, that's just saying that if there's anything else you want to do that might be beneficial we need to agree up front. And other than the problem reports there's nothing that's been tabled so far.	00:46:22	S	[EXP]	Ext			Systems design	minimization of the risk of spurious warnings	D
PFS	Ok, the one requirement in there that said that the spec would … I'm sorry I just spotted it there … spurious, spurious … it's the minimised in there because you don't need a requirement to minimise in it …	00:46:43	S							
AW	The new function shall be designed to minimise the risk of spurious warnings	00:46:47	S							
PFS	Minimise the risk of spurious warnings … so that's not quantitative, how does LR read that? You know because it's this whole thing about, you know, so that's a warning is it? That's classified as a warning?	00:47:10	Q							
GW	It's not a warning, no it's a precaution	00:47:12	S							
PFS	So it should be spurious cautions if you view this as a caution. Right	00:47:19	S							
PFS	What are we doing about that requirement?	00:47:21	Q	[CLA]	Prod					
AW	… That's what threshold is there for, you set a threshold so that if there's any variations in gage and tolerance/	00:47:35	S							
PFS	My question to you GW, is have we gone back and challenged that requirement?	00:47:39	Q	[DEB]	Ext					
GW	No … we have no reason to challenge it because we want these warnings minimised we want as few as possible	00:47:52	A							
PFS	But you could put that risk of spurious warnings shall be in the terms of minus 7	00:47:56	Q							
GW	Could do	00:47:58	A							
PFS	Or in terms of minus 5 … and there are figures against knowing the limit and the point is we can say we can fulfil that requirement whatever, we had spurious warnings every 2 minutes but we minimised that.	00:48:20	S							
PFS	What are we working to as a requirement, what is our belief? I think LR's view on this is if it goes off every flight … it's not good enough. If it goes off once a flight the pilots will ignore it, the first time it goes off in a flight, we'll have to go off twice … so you know you've got an operational problem. Do we have a view on how that's going to, what do we think that is	00:48:47	S							
GW	My recollection is that in design documents there is a reliability target set	00:48:55	S							
NH	For the fuel leak detection, I think it's 5 or something like that …	00:49:00	S							
GW	… Yeah that reliability, I think what we're saying is that we want it to be operational for the failure probability rate of ten to the minus five	00:49:10	S							
PFS	You've got failure to inhibit at ten to the minus five and the erroneously inhibited at ten to the minus five. So you're pretty solid on the inhibition bit of it and we're working on tikity boo …I don't know we're looking at a bit of inconsistency here. I mean right across the leak detection programs	00:49:37	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
MD	We've tried to set thresholds such that they are outside of the normal spec of the box and I think it achieves something like 2 signals, 3 signals something of that order. So if we exceed this … you couldn't put it down to the failure of the gauging, or the failure, you know, the … on the edge of the spec	00:49:58	S	[EXP]	Ext	RR_equipment_spec page 2-10 (followed)	AM/Ca (followed)	Systems design (followed)	minimization of the risk of spurious warnings (followed)	D (followed)
PFS	So what we could say is, can we make a statement, given that the thresholds are set we then say that the gauging would have to be erroneous by this much to trigger the spurious warning and the probability of that is, I don't know, but you can build up some kind of view	00:50:16	Q							
NH	That's fairly common across fuel leak detection	00:50:20	A							
PFS	Right so we've got that, we've got those figures	00:50:22	Q							
NH	They're not written down anywhere, probably imbedded in some other documents somewhere, but they are not brought out in the form of a, if you like, an answer to that requirement	00:50:37	S							
PFS	I'd suggest we need to have a position on that … I think LR is not here but, you know, what do we …	00:50:53	S							
NH	There /the/	00:50:54	S	[DEB]	Ext					
PFS	The spurious minimise would be never, you know, if you say never, that's not true … so there has to be a … to me they put that in but there has to be some kind of view operationally wise.	00:51:05	S							
BD	When it matters	00:51:08	S							
PFS	Yeah that's false alarms, that's missed alarms, it's there when it matters but it's always there when it doesn't matter, then you will miss the one that is there … it's the false alarms, not the missed. So how are we, that seemed to just go quickly to me, how are we cascading that to *Supplier* ?	00:51:29	Q							
PW	We have elected to set the thresholds	00:51:33	A							
PFS	So we are cascading that requirement through the thresholds?	00:51:38	Q							
PW	Effectively, yeah	00:51:40	A							
TT	And in the reliability targets we've set out there are/	00:51:48	S							
PFS	/But those reliability targets don't address this requirement …	00:51:53	S							
GW	The reliability contributes in the sense that if the equipment fails, that fold may cause a spurious warning …	00:52:06	S							
PFS	Yes you are right … it's one of the contributive factors, yes sorry…	00:52:16	S							
GW	We use those loose terms because we are in great difficulty in defining what would be a realistic target	00:52:20	S	[CLA]	Proc					
PFS	Well yeah I guess/	00:52:22	F							
GW	So what we are looking for really, is can you tell us what you can do on the base of the architecture we are working with?	00:52:34	Q							
PFS	Yeah I can go back and catch it in the route 06 terms and say Mr G your number one project for engineering, for chief engineers needs to be more specific for those requirements and here's a good one for you to go away with	00:52:45	S	[INF]	Ext					
TT	I thought the number one project was the quality one …	00:52:50	Q							
PFS	There is a *developed stream* on chief engineers, so … alright, it just makes me nervous!	00:53:00	S							
PW	(…) There's the backstop of the anti MOD, which can turn the fuel leak detection off, and that's always been there as a backstop	00:53:17	S	[RES]	Ext					
PFS	It's obviously not the spirit.	00:53:19	S							
PW	No, quite, but it was put in there as an insurance if you like that if we had these things going off every flight, far too frequently we could turn it off easily	00:53:30	S							
JW	So, if we took the action to look at the threshold we've set and the gauging and produce a field for regularity of the spurious warning we could submit that to the chief engineers for their examination	00:53:41	Q							
PFS	Yeah, I mean *(...)* what's the probability of this thing, you know occurring … I'm just saying you can ask those questions to the team …	00:54:00	A							
[…]	[…]=[jokes about minute taking]	00:54:55	-	[DIG]	-					
RA	The hmm threshold calculation, that is the discrepancy between procedural and what we think we should have, what sort of values do we get from that in normal operations related to reserves?	00:55:11	Q	[EXP]	Prod					
GW	Thresholds are around a ton, aren't they?	00:55:16	Q							
PW	Yeah	00:55:17	A							
BD	…The discrepancy is of an order of about a ton	00:55:22	S							
GW	But the actual threshold changes throughout a flight	00:55:30	S							
RA	Yeah, and what about the normal reserves on the A321?	00:55:37	Q							
NH	…About a ton and a half	00:55:43	A							
RA	It's one you want to be careful of because if you tell them they've got a problem and a leak greater than the reserves it's too late	00:55:54	S							

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Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	And you don't get down to reserves before//	00:55:57	S	[EVA]	Prod	RR_equipment_spec page 2-10 (followed)	AM/Ca (followed)	Systems design (followed)	minimization of the risk of spurious warnings (followed)	D (followed)
RA	//If your flying somewhere, unless you have a lot more than your reserves you possibly won't get there	00:56:02	S							
GW	But that's why this isn't a safety feature, (laughs) this is an additional cautionary indication to how high the crew consider that they may have a fuel leak	00:56:15	S							
RA	Yeah, but it ought to be useful to them	00:56:19	S							
GW	It is, it is, but there are certain circumstances where it might not be as useful signal as others. It's a very simplistic, basic type of monitor, there may even be cases when it's just not operating during the flight because one of the inhibit conditions was set at the beginning of the flight.	00:56:38	S							
RA	Oh yeah I appreciate that, and we always rely on the crew to do their own fuel monitoring//	00:56:42	S							
GW	//That's the basics//	00:56:44	S							
BD	//It doesn't take that away from them//	00:56:46	S							
GW	//that's still the basic//	00:56:47	S							
RA	In fact I understand that, it's the sort of safety backstop, but if you're going to have this hmm caution, it's rather a sick joke to bring it up when they've just worked out that they haven't got enough fuel to get there.	00:57:03	S							
GW	It's no joke obviously, that scenario is pretty much a worst case scenario for us that they don't know about it until they only got that one and a half ton or whatever. Hypothetically it is a possibility, but we had to set a threshold otherwise you increase your spurious warning rate.	00:57:26	S							
RA	I am just concerned whether the threshold is in relation to the reserves and on the A380 recently they would have had the caution coming on and they would have lost more than their reserves when it came on	00:57:42	S							
GW	But I think also that the threshold does reduce as we get towards the end of the flight, so closer to your reserves levels you should get a … is it the other way round?	00:57:52	S							
BD	It decreases	00:57:53	S							
GW	(laughs) oh well anyway	00:57:58	F							
RA	I haven't looked at it in detail but you can see the fundamental crossover point where the caution ceased turning any light on	00:58:10	S							
GW	Any more comments on the specification?	00:58:14	Q	[CLA]	Prod			Systems design	fuel quantity indication shall be inhibited if the FQI is degraded in 2 or more tanks.	D
PFS	I'm just being a bit clueless here but you seem to have the same entry in the left hand corner and in the right hand corner, is that right?	00:58:24	Q							
AW	Yeah, it's a maximum and a minimum … it's a function that uses *(…)*	00:58:39	S							
PW	It's a step function, PFS, and essentially it steps when you add up an ATT or a second ATT	00:58:42	S							
PFS	I'll go through this with you because I don't think it makes sense	00:58:44	S							
GW	It goes back to the point I made, I don't know whether you were in the room at the time, I said that this these requirements would need to be validated for you to be able to sign the spec	00:58:52	Q	[EXP]	Proc					
PFS	yeah	00:58:53	A							
GW	And I think we have to be careful not to get too into the design gist of/	00:58:56	S							
PFS	Yeah no, ok I just … and the final FOB figures are presumably with 2 ACTs aren't they?	00:59:02	Q							
AW	Yeah	00:59:04	A							
PFS	The design requirement 9e) says the fuel quantity indication shall be inhibited if the FQI is degraded in more than one tank	00:59:16	S							
PFS	… Again, I tend to watch out for things like that: does that mean 2 or more tanks?	00:59:24	Q							
AW	Well, more than one …	00:59:27	A							
PFS	Generally I like seeing it as 2 or more rather than more than one tank	00:59:33	S							
AW	Right, OK	00:59:35	F							
GW	I think that requirement will need splitting in two anyway	00:59:37	S							
PFS	Yeah	00:59:38	F							
PFS	… And the other question was really: have you validated the thresholds against the 3 21 and 2 ACTs for that requirement, you made sure that that still holds?	00:59:56	Q	[DEB]	Prod & Proc			Certification & testing	validation of the thresholds for each tank	D
AW	Yes well I think	00:59:58	A							
PFS	You've gone through the specs and …	01:00:00	Q							
AW	Yeah well, I've done it to the point, I've done it comparing the part A for the 3 20 and part A for this one so it's not quite the same format but it's the same … I haven't done the maths but.	01:00:16	S							
PFS	I think you need to … I want to see you validate this for each individual tank. When you do the maths, I want to see this is degraded, this is the maximum error, this still holds under the threshold … and in fact, I might argue that I expect to see some degree of validation from the supplier. That one particularly I think …	01:00:42	S							
NH	What kind of validation would you expect?	01:00:46	Q	[DEC]	Proc					
PFS	Well, if the algorithm works correctly	01:00:48	A							
NH	So if we have an implementation of the algorithm based on these requirements	01:00:55	Q							
PFS	Is that implementation paper based or modelled?	01:00:58	Q							
BD	… Pseudo code	01:01:01	A							
AW	He did it on an excel spreadsheet	01:01:02	S							
PFS	Any action then? anything	01:01:08	Q							
AW	He did a little bit on a basic cell, last time he was down here (…)	01:01:13	S							
BD	Those are comments against the …	01:01:24	Q							
PFS	Well, I'd just like to see a model I suppose, to show they've understood. The injector leak of any sign, any amount, see whether it picks it up (…)	01:01:45	S							
NH	They are popping round tomorrow	01:01:47	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
X	(…)	01:01:57		-	-			-	-	
GW	Ok moving on to/	01:01:59	S							
MD	Just another comment GW, I've noticed that in the safety section we've called up the BS 5501, which I think is now going to be withdrawn. Are we happy that these old specs still stay in there?	01:02:09	Q							
BD	… What would we replace it with?	01:02:16	Q							
EH	There's a new EN spec now. I'll check on it, but I'm sure it's somewhere … Are we all happy the old spec stays in there?	01:02:33	S							
BD	Isn't it one of these things where if the hardware changes we should use the new requirement? … Is that part of EDAT or is that stand alone EDAT. Or if that requirement change directly affects the new hardware, use new requirements … for hardware changes	01:02:58	Q	[CLA]	Ext			Systems design	Safety requirements in case of hardware change	D
NH	This was the same as asking them to develop to ABD 7 or ABD 100, existing requirements/	01:03:06	S							
BD	/ (…) but if they do go and do hardware changes then we've got those new requirements	01:03:15	Q							
NH	OK that falls in the previous requirement that if you do any hardware changes then you will comply with… yeah ok	01:03:22	S							
BD	Where we talk about intrinsic safety, we pull up this : unless hardware changes then do that	01:03:34	S							
NH	Yeah ok (…)	01:03:43	F							
JW	Is ATP part of this document as well? Where is that defined in the 321 FQIC?	01:03:50	Q							
BD	It will be defined by the vendor	01:03:53	A							
JW	Do we accept it?	01:03:54	Q							
JW	There were weaknesses that we identified in smith's ATP, that let problems get through that we weren't capturing	01:04:04	S							
BD	We tend to comment on ATPs don't we	01:04:07	Q							
PW	They are deliverable documents	01:04:09	S							
BD	I don't think we formerly approve them, but I think we tend to accept them	01:04:15	S							
PW	Yeah we do have the opportunity … we do have visibility of these documents but as you say we don't actually approve…	01:04:30	S							
JW	In terms of if there's a weakness in their ATP, what can we do about it?	01:04:36	Q			RR_equipment_spec page 2-10 (followed)	AM/Ca (followed)			
BD	Mmmhh, probably raise comments and twist their arm to change it …	01:04:40	S							
NH	Wouldn't that come under a more rigorous application of what we are asking them to do?	01:04:50	Q							
BD	Not necessarily because the ATP only checks the hardware of the box, it doesn't check the software	01:04:57	S							
NH	Yeah ok	01:04:58	F							
BD	It just proves that the hardware is doing its job	01:05:05	S							
MD	It gives a confidence check for the software but that's as far as it goes/	01:05:09	S							
PW	/that's not stricktly true because often they don't use the flight software.	01:05:12	S							
MD	Yeah you're right	01:05:16	F	[DEB]	Proc			Project management & business	using the supplier's ATP as a fault detection reference	D
TT	But they can	01:05:18	S							
PW	Well typically they don't, they use their own software that exercises all the hardware	01:05:27	S							
PFS	I think what John's talking about is, well one of the things, there's an ATP, right, it's not so much the letting out to me the frustration point, is when a unit is returned from the field with a rejection and all they think they need to do is to put it back to the ATP to declare a 'no fault ' fact and a unit can be returned to the field because the software's wrong and they think it's only an ATP issue because they've checked the hardware error. And if there's no hardware error oh! it goes back in the field and yet you haven't done any diagnosis to know whether your software is irrelevant … now this to me is all about fault finding… now if you are going to use the ATP as a vehicle to do fault detection on a return unit or diagnostics on a returned unit, that's maybe what we are asking for … it's not, it's … do you see what I mean?	01:06:30	S							
JW	Smiths put it in the wrong mode; they weren't going to capture it in the flight mode were they?	01:06:35	Q							
PFS	We'll come back to that ok? I really don't care whether it's an ATP but I want … you want more robust, it's not just verification; you want a more robust process for diagnostics. Because if a unit comes back from the field well it's doing this spurious warning detection things. If they stick on the ATP, well that's alright, the hardware's fine … off we go!	01:06:59	S							
BD	Yeah but on the other hand, if we release software with known problems, which we do … is it therefore going to fail the ATP? …	01:07:15	Q							

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Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	OK I'll have to draw a line under that discussion now, we need to move on	01:07:18	S	[MAN]	Proc	RR_equipment_spec page 2-10 (followed)	AM/Ca (followed)	Project management & business	meeting management: moving to next point	P
GW	Let's move on to the next point of the agenda … this is the review of project plans and the master plan and the statement of work and the program plan we want to talk about at the end. So that leaves us with the fuel leak detection development management plan. That's the next point on here…	01:07:38	S							
[…]	[…]	01:08:03		-	-			-	-	-
PFS	Sorry GW, I'm going to have to leave soon, I just need to ask one last question to Paul: are the requirements of implementation of fuel leak detection of the 3 21 consistent with the requirements we've so far placed on other aircraft and expect to place on future single aisle AC?	01:08:20	Q	[CLA]	Proc			Project management & business	making sure the requirements for this project are consistent with previous ones encountered on similar projects	U
PB	Yes it's very very similar to what we've done to other A/C. I don't think there's any plan of making any other A/C in the single aisle fleet so this will complete the …	01:08:30	S							
PFS	And it's consistent as an implementation?	01:08:33	Q							
PB	It's consistent in meeting the requirements, I think the implementation is subtly different in 3 20 and the other two	01:08:45	A							
PFS	But it's consistent in the requirements … if for some reason tomorrow we say: here is a single aisle A/C implementation for the fuel leak detection, we could lift these requirements and someone, he would not suddenly say: oh gosh this is all different from these, you know/	01:09:00	Q							
PB	We might have a *different look up take* but that would be it, that's the only difference … I think they are consistent in that sense.	01:09:10	S							
GW	I would like to qualify that statement a little bit, yes we are trying to maximize a commonality, and I can use the word maximise!, maximise our commonality on the single aisle fleet, but I suspect there are slightly more difference with the way it has been implemented on the long range.	01:09:33	S							
PFS	Yeah, yeah the long range and 3 80, I said I'm not gonna do that (…) Thank you – PFS leaves	01:09:43	S							
GW	You guys going to swap?	01:09:46	Q	[MAN]	Proc	Management plan document	AM	Project management & business	moving to next document	P
GW	… How do you want to go through this document? Walk us through it and take comments as they come?	01:10:02	Q							
AW	Yeah, that would be the easiest way I think (…)	01:10:22	A							
GW	I'm starting on page one!	01:10:24	S							
GW	Ok	01:10:25	F							
GW	Ok you've just got a summary in there and we'll go over the detail and that can be reflected in the summary in due course but one thing that sprang to mind fairly early on when I started looking at this document was that we'd never picked up on the EP 1013 or GRESS as it's more commonly known. I wondered if you guys had any opinion on the applicability of the GRESS, that's General Requirements for Equipment and System Suppliers because I've seen that referred to more and more regularly in engineering documents. Are you planning on using that or any parts of it?	01:11:16	Q	[EXP]	Ext			Project management & business	GRESS applicable to this project?	P
AW	I hadn't planned on it no!	01:11:19	A							
GW	If you look at this in the AP100 and 200, we say we'd like to apply the spirit of those documents if not actually require those documents and I wonder if the GRESS is not applicable in a similar manner, because from your understanding of all the benefits that are accrued form using the GRESS you are wondering whether or not use features from the GRESS to enhance this particular project.	01:11:39	S							
BD	I think we said that ABD 100 is in effect applicable or as much as we can make it so but ABD 200 isn't. Now if we stick to that then I guess the GRESS also doesn't become applicable because that's where the link would be.	01:11:58	S							
GW	OK	01:11:59	F							
KM	GRESS has already been agreed at Goodrich …	01:12:02	S							
GW	Oh…	01:12:03	F							
KM	Yes, as a general document they have agreed to use it. All equipment is being used on it	01:12:10	S							
GW	New equipment and development projects?	01:12:13	Q							
KM	Hmmm, I would assume so because all the rest and the new parts have already been negotiated with the supplier so…	01:12:25	S							
GW	So they know about it	01:12:28	Q							
BD	Well there's quite an overload there, I mean for a modification	01:12:34	S							
KM	They've already agreed to GRESS for the rest of the parts supplied, so I'll check that.	01:12:39	S							
JW	It's a meaty document with a lot of requirements that aren't really applicable in a lot of places	01:12:51	S							
AW	So that's AP 1013 ... I'll look into it	01:12:56	S							
NH	So do you want us to review whether we want to apply it or do you want commercial to review whether they've already tasked *Supplier* to apply it? Which attack are we taking or both?	01:13:10	Q							
JW	Both I think because it's already in place	01:13:14	A							
NH	So if you can tell us what Goodrich have agreed to implement from the AP and then we'll review the AP and decide whether there is anything that is desirable	01:13:25	S							
JW	Have you got a copy?	01:13:27	Q	[INF]	Proc					
GW	It's on the system	01:13:28	A							
JW	I've got a hard copy if you want	01:13:30	S							
GW	No body will want a hard copy of that (laughs)	01:13:34	S							
GW	It certainly hasn't been a requirement from the chief engineer's office to apply GRESS	01:13:38	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
[…]	[…] = talking between participants about other projects	01:14:17	-	[DIG]	-	Management plan document (followed)	AM (followed)	-	-	-
GW	Ok into the document then … we need to pick up speed a bit …	01:14:20	S	[MAN]	Proc			Project management & business	Meeting Management	P
AW	… Should I read through it?	01:14:31	Q							
GW	Do you want me to skim through it?	01:14:35	Q							
AW	Yeah yeah	01:14:36	A							
GW	Ok we've got the introduction it's a plan so that we make sure we develop the fuel leak detection function. Scope: plan defines the following aspects of the A321 FQIC development for fuel leak detection project: System Development, Configuration Control, System Validation, System Verification, Work Break Down Structure interfaces and dependencies. System Development: definition of task and its objectives, well I think we all know what it's about. Team members, we've got a nice sprinkling of key stake holders in there. Always risky to name individuals because names come and go as the project evolves but it's a start point. Key suppliers/partners responsibilities: Goodrich is responsible for the development of the FQIC (…)	01:15:49	S	[EXP]	Prod			Systems design	systems involved in the final product solution	P
GW	Other systems required for the Fuel Leak Detection Function (…) flight warning computer, ok those of you who are familiar with the fuel leak detection function will know that to get the actual function operating on an A/C you need the FQIC mod which this change is doing but you also need the mod associated with the flag warning computer and display management computer. So what we are identifying here is that there is an associated change with the flight warning computer as well which needs to be taken on board and below that the display management computer, we are starting now to identify the individual standards of those computers that need to be on board the A/C to get the function enabled.	01:17:00	S							
BD	Does it need to mention the pin programming? In terms to hold it on and off …	01:17:11	Q							
GW	I thought the pin programming was on the flight warning computer. That was wrong?! So you think we might be lacking a computer there then?	01:17:23	Q							
BD	Yeah there's a sort of box, yeah there's something else.	01:17:25	S							
MD	Quick point there: do you have the mod number? There's a six figure number here for the DMC.	01:17:36	Q	[CLA]	Prod					
AW	For the DMC?	01:17:38	Q							
MD	310565	01:17:40	A							
BD	I think there's an extra 1 there, it's the 1 which is wrong	01:17:44	S							
AW	Yeah ok I'll check that one	01:17:46	S							
JW	And for the Flight Warning?	01:17:47	Q							
AW	I didn't find the number, but I'll try and get it.	01:17:52	A							
GW	Configuration control, ok, using the standard configuration system, documentation system. Not so much configuration control as an archive, but quite a good one. You're not anticipating anything more complex than that?	01:18:14	S	[CLA]	Proc			Aircraft configuration & architecture	configuration control	P
NH	We don't need to *endure* anything here do we?	01:18:17	Q							
GW	Not on this project no	01:18:22	A							
GW	Ok then, you're listing a number of key documents, which is fair enough. Inputs to the task.	01:18:30	S	[DEB]	Proc			Project management & business	list of key documents for completion of the project	P
BD	Shouldn't these documents be identified at specific issues … one says to be updated but …	01:18:37	Q							
GW	If there isn't an issue identified then the standard is to assume that it is the latest issue, isn't it?	01:18:44	Q							
BD	Well we don't write our specs that way, it's very specific.	01:18:50	S							
GW	If they are likely to say that we are working to an earlier issue of a document then you should be specific. For completeness you could put the issue status down.	01:18:58	S							
GW	Of course you know the problem, then … when those documents get reissued this has to get reissued.	01:19:07	S							
MD	But if you don't put the issue down (…)	01:19:13	S							
[…]	[…] = talking between participants about various document codifications	01:20:24								
GW	So we've got those documents, it's just a reference list really. Outputs from the task …output or input? Gone for output. Equipment Specification, Definition of ARINC, Maintenance Messages Broadcast …well/	01:20:41	S	[RES]	Proc					
BD	I think one of the documents listed in other, the configuration index should be in there, because it's a top level pointer	01:20:50	S							
JW	It's in the next block though.	01:20:53	S							
BD	Yeah, but I believe that we can move it up	01:20:55	S							
GW	To be honest, in reading that list, I lost the understanding of what was an input and what was an output, why there were other documents because documents are surely an input or an output of something. It's a list of documents isn't it really? So I would think about how you want to break that down, it's editorial	01:21:16	S							
AW	I was looking at key documents and their documents but that were not part of the equipment spec	01:21:21	S							
GW	But one of the key documents that I looked for, I couldn't find that was the DDP as an output.	01:21:30	S	[CLA]	Proc					
BD	These are a list of AUK documents aren't they? I don't think it actually says that but I think that's what has been described	01:21:43	S							
GW	Oh well that would explain why there's no DDP.	01:21:46	S							
AW	It should be in the approval dossier	01:21:47	S							
JW	Yeah there are a lot of documents that are in the statement of work.	01:21:50	S							
AW	But I've still not got any DDP in there anywhere	01:21:54	S							
BD	You haven't mentioned the whole document set from the vendor	01:22:01	Q	[EXP]	Proc					
AW	No, no	01:22:02	S							
TT	There's software insurance activities in there	01:22:06	S							
GW	That's the problem with these things; you never know where the list ends. So the only way to get around it is to be specific up front about what this list of documents is meant to be and then you can put a fence around them and then people wont start wanting to add pigeons… ok better move on!	01:22:28	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	In the next section, validation then. Objectives of this validation plan: identify potential deficiencies in the requirements, limit potential for unintended functions in the system, and ensure appropriateness for the requirements for the system. Ok very good.	01:22:46	S	[DEB]	Proc	Management plan document (followed)	AM (followed)	Certification & testing / Project management & business	V&V responsabilities	P
BD	I though there was something missing there. I would have put assume high level requirements are met completely and correctly somewhere in there.	01:22:54	Q							
GW	Assume? Did you say?	01:23:00	Q							
BD	Well … ensure … I can't read my own writing, maybe it's ensure!	01:23:06	S							
NH	(…) Make sure the requirements are implemented correctly?	01:23:31	Q							
BD	No …Validation is just ensuring that each step is …	01:23:44	A							
GW	Next item: responsibilities for validation of FQIC requirements lie with the FQIC vendor. I think that falls quite short of the mark to be honest because we are responsible for validating it in our requirements and they are responsible for validating in their next level of requirements. I think you might want to expand that a bit. Particularly this is another opportunity where I would need to see a definition of what we require them to do. In this management plan I would like us to be saying what sort of validation we are going to request the supplier to do.	01:24:30	S	[EVA]	Proc					
AW	ok	01:24:31	F							
GW	Picking up on what I was saying earlier for the specification, it's a, I think it's not really useful to just say *Supplier* are responsible for validating requirements. In what way? To what level? How much? … As a customer for this particular document, I want it to make me feel comfortable with what we are going to do, to make me confident that we are going to have a mature product at the end of the day.	01:25:02	S							
AW	sure	01:25:03	F							
GW	It's a similar comment for the verification section I suspect in the end	01:25:06	S							
MD	Would you … continuing onto that theme GW, you talked about putting something similar in the part A spec, these have obviously have to be telling the same story?	01:25:17	Q	[DEC]	Proc					
GW	Yes	01:25:18	A							
MD	Do they need to be going into one place or both?	01:25:20	Q	[EXP]	Proc					
GW	Well this is saying, for this project this is what we intend to do and this is the sort of thing we are going to tell *supplier* they need to do. What we need to reflect is how Supplier goes in the spec.	01:25:32	S							
MD	We need to paraphrase the part A	01:25:34	S							
GW	Well in effect this goes before the part A … and paraphrase what's at the end of the spec.	01:25:43	S							
AW	It kind of ensures it's at the top of our mind doesn't it?	01:25:45	Q							
GW	…yeah you're getting the idea. OK?	01:25:48	A							
GW	So AUK will perform a number of validation activities which are detailed in the spec in 5.4 …	01:25:54	S							
AW	That could be a typo …it's supposed to be 4.4	01:26:03	S							
GW	We'll come to that. That line gives us a good idea of what we intend to do ourselves.	01:26:14	S							
GW	Another list of key documents inputs and outputs … the following documents are involved in the validation process. For issues of the documents see the configuration index ref 'that' issue 5. Ok so these are all existing documents. So AUK we've got all those and *Supplier* we've got equipment part B, Plan for Software Aspects of Certification (PSAC) and Equipment Design Evolution Sheet …	01:27:03	S	[CLA]	Proc			Certification & testing	V&V plan from suppliers	P
AW	Sorry?	01:27:04	Q							
GW	*Supplier* produced a plan for software aspects certification, that's an input is it? Or is it an output?	01:27:12	Q							
BD	An output to them an input to us!	01:27:17	S							
GW	Definitely both …	01:27:26	S							
GW	The reason it comes to the forefront of my mind is that it made me think of the V&V plan. If they are going to send us their plan for software, I would also expect them to send us their plan for V&V.	01:27:38	S	[RES]	Proc					
MD	… We should have the complete set	01:27:48	S							
GW	Be careful there, I want to know what their plan is for Validation and Verification of the complete equipment …If it's in there that might well be fine (…)	01:28:15	S							
GW	Get that message across: Validation and verification plan please!	01:28:19	S							
GW	So then we've got the outputs, we've got the minutes and closed actions from the following reviews. It could be the closed actions in there and quite often we place action and we forget to follow up on them. So make sure we get them accomplished. So a concept design review, a preliminary design review, a critical design review a first flight review. Would that first flight review be the test readiness review?	01:28:46	Q	[EXP]	Proc			Project management & business	design review planification	P
AW	Well in fact yes, but specific for a flight test not for a rig test so we split them in two different boxes	01:28:54	A							
GW	So are you going to have a test readiness review in its own right?	01:28:59	Q							
AW	It would be a good idea wouldn't it!	01:29:05	S							
GW	You see, first flight review, for me if you did a test readiness review, test readiness for first flight is just one small part … rather than having a flight review	01:29:17	S							
MD	The only thing is, where we've fallen over in the past is when we haven't been able to make a clear statement as to whether the system was safe for first flight and personally I prefer to see a very explicit, you know, milestone at that point to ensure that our team can make the appropriate statements. We haven't always been able to make those statements but if the software is not complete at that time then can you say that the system is safe?	01:29:54	Q	[DEC]	Proc					
GW	So recommendation then would be a test readiness review before we start testing the equipment and a flight test readiness review prior to flight. That's fair enough because we do request flight limitations certificates so it would be a good opportunity to get those resolved as well.	01:30:11	S							
EH	Moving to the ABD there's a FDR First Delivery Review …	01:30:16	S	[CLA]	Proc			Project management & business	FDR review	D
TT	Well first delivery test readiness… it's the same thing /I think/	01:30:23	S							
EH	/I see/ it's ABD terminology …	01:30:25	S							
JW	Cert readiness review is not there either?	01:30:30	Q	[CLA]	Proc					
TT	No that's not an essential one … we cover that from a software point of view … but not overall.	01:30:42	A							
NH	It isn't meant to be a list of all the reviews we are going to have, it's in relation to validation … the requirements validation. The actual management plan should dictate what actual requirements we are going to have; these are only the ones that will contribute towards validation.	01:31:02	S							
BD	The other things are more verification.	01:31:04	S							
NH	Things like test readiness review and flight readiness review, I would have thought contribute to verification	01:31:12	S	[DEB]	Proc					
JW	They are not on there either	01:31:15	S							
NH	But you're right, there isn't a list	01:31:19	S							
JW	They are not in on the document	01:31:22	S							
AW	…yet!	01:31:23	S							
GW	… And then we've got the outputs from *Supplier* which you've just added, documented as completed actions from these reviews. If one of the inputs from *Supplier* is a V&V plan, a Validation and Verification plan, then one of the outputs would be their actual results (sneeze).	01:31:49	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	Then we move on to a description of the AUK validation activities and if anyone has additional comments just barge in otherwise I'll just keep going on. The following validation activities are aimed at achieving the objectives stated in section 6.1.	01:32:07	S	[CLA]	Proc	Management plan document (followed)	AM (followed)	Certification & testing	rationale for the AUK validation activities	D
AW	There's probably some typo…	01:32:10	S							
GW	Where are they?	01:32:13	Q							
PW	Have you learnt to use links?	01:32:19	Q							
AW	Well … yeah	01:32:20	A							
GW	And most of our validation activities evolves around design reviews … 4.1 there's no modelling activities, no preliminary tests, prototype tests or anything … no	01:32:34	S							
AW	no	01:32:35	F							
GW	Just reviews, and then you go and say we'll do a concept review, a preliminary design review, critical design review and production of a validation matrix	01:32:46	S							
AW	I've actually missed out this one as well because in a way it's a validation exercise as well	01:32:50	S							
GW	Validating requirements	01:32:52	S							
AW	… are my aims for these meetings in the right ball part because I'm not sure what that point was. I knew that I had to put them … (laughs)	01:33:08	Q	[EXP]	Proc					
NH	Refreshingly honest! Who is going to be able to tell him that?	01:33:16	Q							
JW	They are carried in the policy documents	01:33:19	S							
GW	They are fine in terms of definition of what the reviews do, but you can refer to the single aisle policy document or you can go to the APs … I can't remember their numbers now …1036 and the like. They are pretty consistent definitions. What you actually achieve in those in terms of validation depends on the actual review itself, but you are validating that your requirements are still being achieved at each of those levels, it's not an issue/	01:33:48	S							
MD	/You could use 2288 … which would be appropriate	01:33:52	S	[INF]	Ext					
AW	AP 228?	01:33:55	Q							
MD	AP 2288	01:33:57	A							
AW	2288 … smashing, thank you	01:33:59	S							
GW	That's that then	01:34:00	S							
BD	Oh GW! You're pulling my leg, it's the system top level document now, it's the one that calls up the ABD 100 and 200, so it's the …	01:34:09	S							
PB	What's the title: System …	01:34:17	Q							
BD	System and equipment development and requirements, it's the systems top level document	01:34:24	A							
GW	These APs and AMs when they are formally created they are not flown down to projects?	01:34:31	Q	[CLA]	Proc			Project management & business	procedures and methods guidelines implementation in AUK projects	D
MD	We are actually doing roll outs of projects, we've done A400M and we're doing A380 now … If you can think of a good way of getting it into a project, into the team where you are then we've got half a dozen slides which just describe what the document is, how it fits in with everything else and how it calls up ABD 100 and 200 and an appropriate documentation that fits with them. Your help would be appreciated.	01:35:07	S							
GW	Ok, moving on: verification, "objective of the verification plan: is to define the activities to confirm the solution to the requirements placed upon the FQIC development. Responsibilities for verification. AUK: supplier documentation review by relevant specialists, system verification exercises performed on the AUK test rig at Filton and on the aircraft in either Hamburg or Toulouse" … that's very brief, I reiterate my comment about validation. I would really like to see the "this is what we intend to do"	01:36:02	S	[CLA]	Proc			Certification & testing	approach for the verification of the design by AUK	P
AW	I've sort of got it in 5.5	01:36:04	S							
GW	Oh sorry yeah, 5.5	01:36:06	S							
AW	And in section B, where I've stuck it into a validation and verification matrix which gives a bit more detail …	01:36:12	S							
BD	I've got an issue with the objectives, the second statement says "requirements placed upon the FQIC come from the Airworthiness Authorities and are defined in the certification plan", partly true but the requirements come from somewhere else as well …	01:36:26	S	[DEB]	Ext					
AW	Well the certification requirements come from airworthiness … maybe the statement was too general	01:36:42	S							
GW	OK you can put that right. Supplier: "*Supplier* will perform verification at software module level" that's falling short of the mark as well: they are verifying the equipments at module level, at module integration, at hardware / software integration … basically they are doing software testing, equipment testing, system testing. That's my view of it.	01:37:05	S	[EXP]	Ext					
NH	Are they doing any systems testing?	01:37:07	Q							
GW	I believe the specification is for a system isn't it? Not just box / subsystems.	01:37:13	Q							
EH	It's not considered to be an equipment though, it is a system …	01:37:17	S							
BD	I think we had the same question with Paul on the 319 CJ spec . I think it turned out we called it equipment. Some requirements were for equipment rather than for the system or effectively a sub system/	01:37:37	S							
GW	/Ok let's not get confused with the terminology here, we need to be sure that the software does what it is supposed to do, but we need to make sure that the software does what it is supposed to do inside the box, i.e. that the box does what it is supposed to do and we need to ensure that the box does what it is supposed to do when it is interfaced with the rest of the fuel system, i.e. fuel probes for example.	01:37:55	S							
BD	That's a subsystem in effect	01:37:58	S							
GW	If that's how you want to turn it. We don't want to find that we've got a problem and actually put it on an A/C and integrate it!	01:38:07	S							
TT	You've got the supplier now that's *Supplier* , when in fact the software supplier will probably be *SupplierB* .	01:38:12	S	[INF]	Ext					
JW	*Supplier* has contracted them?	01:38:15	Q							
TT	Yeah	01:38:16	A							
JW	(…) but it's still purely *Supplier* 's responsibility	01:38:25	S							
BD	(…) *Supplier B* supply a box to *Supplier*	01:38:48	S							
GW	Ok right, that's that, *Supplier* is a primary contact for us on software/ hardware for the equipment. We need a better definition of what we want them to do in terms of verification and again that will interrelate to what you put in the specs.	01:39:08	S	[EVA]	Proc					
GW	And no verification testing is expected by the partners to confirm the compatibility of the FWC and DMC. The rationale behind this statement is that because the FWC and DMC are common to both A320 and A321 type aircraft; the same ARINC labels as implemented on the A320 FQIC for fuel leak detection can be applied for the A321 FQIC. Say if it works on the 3 20 it will work with this box?	01:39:39	Q							
AW	They are the same labels, we expect the same inputs, the labels, the words are the same.	01:39:52	S							
GW	But we will verify that through an A/C test anyway	01:39:55	Q							
AW	Yep, well that's the first time there no opportunity to do a hardware test (…)	01:40:05	A							
GW	Ok then you identify the verification program	01:40:07	S	[CLA]	Proc					
BD	Before we go to the 5.2 should we be performing some flight tests as part of the verification?	01:40:17	Q							
JW	Well that's what it says here: "and on aircraft at either Hamburg or Toulouse"	01:40:23	A							
GW	And they make them out in section 5.5 …excellent	01:40:33	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	Well key documents, inputs and outputs, well we've discussed the listing of documents and again I would say that there's a certain lack of reference to test plans … and I would like to flag up that with regard to flight test request, you will need to consider whether we'll need a development flight test or a certification flight test. We've experienced problems in the past where certification flight test is a specific flight test to collect evidence for the authorities for the certification activity, development flight test you may want to do different types of flying to collect different types of data, so bear that in mind please.	01:41:23	S	[EVA]	Res	Management plan document (followed)	AM (followed)	Project management & business	type of aircraft included in the project	P
NH	Presumably this is where we specify that we need to do it on ACT and non ACT A/C?	01:41:28	Q							
AW	We need two separate …	01:41:30	S							
AW	Well (…) an ACT A/C might capture both.	01:41:38	S							
GW	These are the sort of things that you should be thinking of for when you want to do it …particularly if start talking about variations within ACTs, because we have to try and make sure that we have an A/C available that we can use and if we are talking about doing testing in about a year's time if you tell us now we might actually be able to sort it out! If you tell us a month or two before you are required to do the testing forget it!	01:42:02	S							
AW	Yeah ok	01:42:03	F							
GW	We need to get some idea of getting our FTRs Flight Test Requirements out	01:42:09	S	[EVA]	Proc					
JW	You've got it quite early in your plan though, it's January isn't it for the FDR …	01:42:19	S							
GW	Then you've got a description of AUK verification activities, one general comment that I would make is that I think we need more details on what we intend to do here, these one line statements are fine but it doesn't tell me a great deal, the first one we've got is just an example: "Rig testing in accordance with a Rig Test Requirements document (to be updated to include suitable Fuel Leak Detection and Dry Bay Deletion tests)" ok, that's fine in what you say but how many hours are you going to do on there, what sort of maturity testing are you going to do, are you going to run it for 100 200 hours, in flight, on ground?	01:42:58	Q	[DEC]	Proc			Certification & testing	Detail of the verification activitites.	P
AW	That can come in this document? That's the best place to put it?	01:43:01	Q							
GW	It's a start point; it's to give us a feel for the level of rigor you want to apply.	01:43:07	S							
AW	ok	01:43:08	F							
GW	When you do this early it makes you think up front what you want to do … so rig testing, flight testing, different types of testing pre selected fuel, design clearances, FQI calibration consult GTRs, possible ground test … yeah that's great, I mean at the moment putting what you think we need to do, we can always take things out …I'd rather see things in here and take them out later than trying to add them in. It's a lot easier to cancel an A/C than to arrange it	01:43:43	S							
GW	"A Verification Matrix providing full traceability of results for each verification" so this matrix against each requirement there will be … how are we to respond to … and this matrix will also cover those elements of the spec that didn't change, will we still be checking that the unchanged parts work	01:44:06	Q	[EXP]	Ext					
AW	In general yeah, generally	01:44:08	A							
GW	So the test coverage will be complete not just for the parts that have changed.	01:44:12	S							
GW	So at this point it also sprang to mind again, at this time we also need to define what we need in terms of the supplier for maturity testing whether that's a software, equipment or system level, what sort of operational test will be required, ground flight, how many hours … in fact that's what we've been doing with SupplierX, SupplierX can now come to us and say: "we've been testing this new kind of computer for 1000 hours.	01:44:44	S							
AW	(…) Well, yeah that's my next point, there was actually an appendix A (…) but it seems like I really should have left it in there for referencing purpose	01:45:18	S							
GW	Then we've got a work breakdown structure, if anybody identifies anything that's missing then let AW know, and I'm sure it's just a record of the different types / part of work we need to do. Then we've got a (…) table	01:45:32	S	[CLA]	Proc			Project management & business	Verification plan	P
AW	(…) it's because it's A3, it's an ingenious method that	01:45:45	S							
GW	And the intention of this table is … what?	01:45:50	Q							
AW	Well, it's to get *the ball rolling* on the verification matrix	01:45:53	S							
GW	Ah OK, so it's your start point	01:45:55	S							
AW	Yeah it gives you a bit more detail … well only a bit more detail on a … how we are going to verify specific functions such as dry bays, fuel leak detection and a little bit about … just everything else.	01:46:13	S	[EVA]	Proc					
GW	Ok	01:46:15	F							
EH	On the table AW/	01:46:17	Q							
AW	/yeah/	01:46:18	A	[RES]	Proc					
EH	/page 11, and the column AUK rig test, systems test; second sentence you've got: "any that can' could be monitored for 'non-intended function'", I assume you meant "can't" …	01:46:32	Q							
AW	Hmmm that's a good point [reading to himself], yeah you're right	01:46:37	A							
BD	Well that's an incomplete sentence, isn't it …it doesn't actually say anything	01:46:40	S							
EH	In the next paragraph you've got "dry bay detection" rather than "dry bay deletion"	01:46:45	Q							
AW	Smashing …dry bay	01:46:49	A							
EH	And on the front sheet you've got 1559 and on the other sheets you've got 1599…	01:47:07	Q							
AW	Oh yeah … a little more confusion! Smashing thank you	01:47:12	A							
EH	Then on page 6, just above Goodrich, you've got "complied" when I think you want "compiled" there	01:47:27	Q							
AW	Yeah I believe I do (…)	01:47:28	A							
GW	But AW will be open to take any comments on these documents.	01:47:45	S							
GW	The next document we've got is the certification plan and since this is a requirements review, it's a little bit early to be reviewing the plan. But just a couple of points; I'll take this opportunity as it's part of the pack	01:48:02	S	[INF]	Proc	Certification plan	AM	Project management & business / Certification & testing	Certification plan	U
AW	It was set as a deliverable for phase 1.	01:48:05	S							
GW	Ultimately you will have to go to Jean Philippe Tarez in Airbus central.	01:48:14	S							
GW	First point that came to my mind and looking at it is that you refer in here to the ARP 4754	01:48:24	Q	[EVA]	Ext					
AW	Yeah	01:48:25	A							
GW	And I wondered where that comes into this job? …it makes me feel a little bit nervous because applying that requirement to this job would require you to do a lot more work than you've currently done	01:48:46	Q							
AW	Right … ok you've caught me up there on updating this from the A320 there without thinking that through properly …	01:48:53	S							
GW	Did we have that in the plan for the A320?	01:48:56	Q							
AW	Yeah … to a certain extent	01:48:59	A							
GW	To a certain extent?	01:49:01	Q							
AW	Well in the extent that we did it after the event, we kind of reversed engineered a few times and then basically I just based that on that document that Lonnie produced which had it in there, so I got caught out there	01:49:16	S							
GW	I think you've got to be careful not to be pulling a knot, if you are going to put it in there then we may have to revisit the work plans for this job …where I would like to see your requirements management tool for example.	01:49:31	S							
AW	Ok it's good to know, it's better to take it out	01:49:34	S							
BD	There no mention of it in, as far as I can see, in the part A as one of the listed documents	01:49:42	S							
AW	Ok, thank you	01:49:47	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	(…) We've been picking up earlier on how we use words, there's another one in here … "the existing" …"the new sof"…	01:50:08	S	[INF]	Proc	Certification plan (followed)	AM (followed)	Certification & testing	Wording in section 3 of the certification plan	U
PW	Where are we GW?	01:50:09	Q							
GW	I'm in section 3, second paragraph, "The new software for the additional functionality will be developed to D0178B level B." ok fair enough "The existing software that is proved unaffected by the development will continue to be applicable to the existing DAL level" ok how are we going to prove it?	01:50:32	Q							
BD	… You just delete the word prove, don't you?	01:50:38	Q	[DEB]	Proc					
PB	It's part of the process actually for a level B exercise, you do a … traceability exercise to show that the interface has been covered and that there's no conflict between software components and they don't affect the change, so you're effectively doing a regression exercise.	01:51:05	S							
GW	What you're telling me then is that there is a process defined in the requirements document for doing that proving? … If I said that is proved by following the process in DO178B …	01:51:21	Q							
PB	Yeah that is effectively what DO178 level B says …so I think that that statement is fair … prove? … does that prove … you may take exception of prove, but that sentence is fair	01:51:43	S							
BD	Does that process tell you which modules change and which don't?	01:51:47	Q							
PB	That process should give evidence, yes … objective evidence of it yes.	01:51:52	A							
BD	(…) Is there an exercise they do, that says well on these requirements it forces changes on modules 1, 2 and 3 but not 4, 5, 6 and 7	01:52:12	Q							
PB	Well the analysis of what they need to change is obviously part of the process, what we have to make sure is that nothing else is changes other than what they say has changed, and what they say has changed has been developed in the right path	01:52:31	S							
BD	Does that also ensure that a module that shouldn't change hasn't?	01:52:41	Q							
PW	Well we would have to check that as part of our design review	01:52:48	S							
PB	Yeah well I mean it's all part of the test, the requirements traceability and test coverage analysis	01:52:59	S							
NH	It's nothing to do with the test coverage or monitoring?	01:53:02	Q							
PW	It's combination of test coverage and code …analysis of the source code	01:53:19	S							
GW	Ok I think we can back out of that now, it's just that there's in there the word prove, which seems to raise questions with me … the rest of the plan is fairly standard for the certification plan, telling us what the certification basis is and the plan means the compliance(…)	01:53:44	S	[DEB]	Proc			Project management & business / Certification & testing	Validation of the certification plan	U
EH	There's a contradiction in the paragraph in section 4 mentioned after the JARs, which mentions "At issue 1 of this plan, the probability of a hardware change is very unlikely" we're in paragraph 3 so there'll be no hardware changes …	01:54:02	S							
PB	I think GW is right I don't think you can assume that the certification plan is going to be mature at this meeting but we ought to ensure that there is a meeting where a more appropriate review of that certification plan can be held and by that time I hope it will be mature.	01:54:25	S							
GW	We do do that in the certification readiness review	01:54:28	S							
PB	… I know GW, I know we do but that is a bit late, is there not another appropriate place in your plan that you could take where the items could be part of a certification plan.	01:54:43	S							
GW	By the time we get to the critical design review we should be pretty firm on those things	01:54:47	S							
PB	I agree we need to do it for the CDR	01:54:50	S							
AW	*Review 2 of this one*	01:54:56	S							
GW	… We've now overshot our time schedule … everybody happy to continue? I propose that we don't dwell on this certification plan, it's still to be worked up, and I just needed to get certain points off my chest. The next item we've got then … risk register then, yeah?	01:55:33	Q	[MAN]	Proc	Risk Register	AM	Project management & business	Meeting management	P
AW	yeah	01:55:34	A							
GW	Would you like to walk us through this then?	01:55:38	Q							
AW	(…) Do you want me to go through all of them even the closed ones or?	01:55:53	Q							
GW	Just briskly, what they are	01:55:56	A							
AW	Alright, so the first one was a hardware change is required cause of that will be an inadequate capacity to handle the fuel leak detection function and dry bay deletion function, but we think that's closed based on the fact that *Supplier* have stated that it's not the case …	01:56:12	S	[EVA]	Prod			Project management & business	Risk assessment for hardware change	P
GW	ok	01:56:13	F							
BD	So there's still a small risk like 1%?	01:56:17	Q							
AW	I suppose it could be open I suppose until …	01:56:19	A							
GW	It's open or closed … Are you now confident that it's just a software change?	01:56:26	Q							
AW	Yeah	01:56:27	A							
JW	There's no risk	01:56:29	S	[DEC]	Proc					
AW	Next one is Goodrich will not have resource available to work on FQIC, cause was other business commitments, I left that one open because we still haven't issued the part A, so they still haven't finalised all their plans to support us.	01:56:44	S							
GW	It's quite a low risk	01:56:46	S	[EVA]	Proc			Project management & business	Risk assessment for supplier resources	D
JW	*Supplier* said nothing to you? …They are aware of that because they are coming tomorrow?	01:56:56	Q							
KM	Yeah still waiting	01:56:58	A							
AW	The next one was the equipment spec is not accepted by Paul (…) although he didn't agree on it formerly Chris and Lonnie agreed on his behalf.	01:57:30	S	[DEC]	Proc					
JW	It's still a risk …	01:57:31	S							
AW	Next one was phase 1 plans rejected but they were accepted	01:57:46	S	[EVA]	Proc			Project management & business / Certification & testing	Risk assessment for rejection of phase 1, for the condition of the AUK test rig and for the development according to DO178A or B	P
AW	Next one : FQIC can't be declared two ways interchangeable because of standard default function	01:57:56	S							
AW	But they have been, so that's that	01:58:00	S							
AW	The A321 test rig at AUK does not work correctly, cause: accident or damages occurred since the rig was lat used. But we've done some investigation testing on the rig and it seemed to work fine although there's still an action to a …well it should be open really because there's still point 2: commission the test rig after they've done some updates for the 321 …	01:58:32	S							
NH	There's always a chance…	01:58:35	S	[EVA]	Ext					
AW	Exactly …	01:58:36	F							
AW	Ok the risk to do with software development at our level DO178A although it should be level 2 shouldn't it? DO178B it's level B … I've actually put that one as closed for some reason	01:58:58	Q							
MD	What are you looking at?	01:59:03	Q							
MD	Level 2 could be B or C, there isn't a risk that it could go to A and therefore I could argue that there isn't a risk … as long as everybody agrees to B	01:59:11	S							
GW	We are going to change the software aren't we?	01:59:15	Q							
MD	Yes but remember that the whole software needs to be DO what's it's name B compliant even the bits that haven't been opened … but from then on any time you open you have to do it according to…we have to do whatever change to B because the same rules apply. It's a particularity but that was the only way to proceed. You can't expect for a minor modification for every module to be tested … so it's the only way to go. But as soon as we certificate that software, it will be certificated against DO178A the whole thing	02:00:14	S							
GW	Ok	02:00:15	F							
MD	So for me that risk is actually closed	02:00:25	S	[DEC]	Proc					
GW	Ok	02:00:27	F							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
AW	So ok delay between phase 1 and phase 2, phase 1 being this and phase 2 being the detailed engineering work … of course resource, availability, plan rejection or priority clashes	02:00:45	S	[DEC]	Proc	Risk Register (followed)	AM (followed)	Project management & business	Risk assessment for delays between phases 1 and 2	P
GW	Well we are already having a delay aren't we...leave it open for now	02:00:48	S							
AW	(…) A321 test rig , they are moving into a new building that means that it is not available for the test, but I was assured that they wouldn't move it until the test rig is finished, that won't apply to any in service testing we need, if there's a program running then it would be moved at a later date (…)	02:02:07	S	[CLA]	Res			Project management & business / Certification & testing	Use of the test rigs at AUK	P
AW	Where was I?	02:02:08	Q							
GW	15	02:02:09	A							
AW	15, A Delay could be added to the project because of the updates to the test rig, cause: there are new function that require update of the test rig or update by structures CoC and they may not have the time	02:02:25	S							
BD	It's for the dry bays on the rig?	02:02:27	Q							
AW	Yeah basically they have to write a bit of software that Les' group don't do, basically we have to contract it to structures and they do it for him. So I put down as mitigation to provide Les with MOD instructions as soon as possible.	02:02:42	S							
GW	Is there any risk that if you are giving them the requirement to change the rig as soon as possible that the requirement you are giving him might be wrong?	02:02:53	Q							
AW	It depends what the change is, I believe the change is... no it's not just look up tables. Ok I'll look into it	02:03:05	S							
EH	I don't know because I can't read these very well, I was considering dropping another risk on the dry bay definition itself which I think John's got anyway which I think impacts this one as well…	02:03:20	S	[EXP]	Proc					
GW	So the top dry bay deletion requirement may change?	02:03:23	Q							
EH	yes	02:03:24	A							
AW	Ok 16: Updates to FWC and DMC may have an impact on the FQIC Fuel leak detection function.	02:03:38	S	[INF]	Prod			Project management & business	Risk assessment for the impact of updates to FWC and DMC	P
GW	I'm afraid I'll have to ask to stop a bit, it's getting into that time …	02:03:44	S	[DIG]	-					
NH	… of heavy traffic [background noise]	02:03:46								
AW	The cause of this one is that the flight upgrades to the computer the AP for fuel burn that we plan to do on the FQIC of the 321 but we're not sure what/	02:03:59	S	[DEC]	Proc					
TT	That's all clear	02:04:01	S							
AW	Is it …that's closed is it?	02:04:03	Q							
GW	Yeah ok	02:04:05	A							
AW	Special support may not be available due to ongoing A320 venture…	02:04:26	S	[CLA]	Res			Project management & business / Certification & testing	Management of the testing process with current test rig capabilities	P
BD	Isn't that one a duplicate of the one above somewhere	02:04:27	Q							
AW	Might well be …	02:04:28	A							
BD	Very similar	02:04:29	S							
NH	That was for *Supplier* I think: resource availability.	02:04:33	S							
JW	You've got two development plans and two rigs, they are pretty much in parallel from what Smiths' presented today, what they want to do on the FQIC for the 320/	02:04:50	S	[RES]	Res					
AW	And that would run at the same time than this one, yeah?	02:04:52	Q							
JW	Yeah	02:04:53	A							
AW	So we do have a problem then because we only have one person that can run both of those rigs and only one of those rigs can operate at any one time because they use the same set of computers … so we're going to have a clash there aren't we?	02:05:09	Q							
BD	If you're planning to run shift testing on the rig you'll need more personnel to run it	02:05:17	S							
AW	Ok (…)	02:05:41	F							
AW	Next one is dry bay deletion can't be certified until an aircraft test can be performed, basically we can't close the project until we've done our flight test or an aircraft test on dry bay deletion so that really is certainty, but I thought I'd mention it to make sure everyone is aware of it.	02:06:04	S	[EXP]	Proc			Certification & testing	Risk assessment for certification issues	P
JW	We could certify the computer though with the functionality in it?	02:06:08	Q							
AW	But we can't certify the function itself	02:06:10	Q							
JW	No	02:06:11	A							
AW	We can't really certify the/	02:06:15	S							
BD	The dry bay mod will call up separate/	02:06:19	S							
JW	Then programming and then they'll have the flight test … or ground test most probably	02:06:25	S							
NH	Rotate it for dry bay deletion/	02:06:27	S							
JW	Will be done under part of the dry bay	02:06:29	S							
NH	We'll have to remember that when we implement dry bay deletion … we'll have to remember that it's not because the computer is working that we can automatically certify the function.	02:06:50	S							
BD	Is there a similar risk regarding ACTs? If we haven't tested on ACTs can we certify this on ACT airplane?	02:06:59	Q	[DEC]	Res					
JW	We can't have a flight test aircraft available to meet our requirements … That's the risk	02:07:07	S							
AW	… And finally, but this might be replicated elsewhere, the delay of the issue of the part A which would probably include the delay between phase 1 and phase 2. But I still put it down as a separate risk	02:07:33	S	[EVA]	Proc			Project management & business	Risk assessment of the delay of the issue of part A	P
JW	When do you think you can resolve that one?	02:07:39	Q							
AW	I was hoping by the end of this week but it seems very unlikely, I've got to get hold of Phil and Paul S.together, to sign it	02:07:51	S							
JW	And to get their comments	02:07:53	Q							
AW	Yeah I've had their comments and implemented their comments but Phil still has a couple to go or he wants some more assurance so it's going for the end of this week but it's more when I can get hold of them … and that was that.	02:08:11	S							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	You've got 2 new risks to put on our sheet/	02:08:14	S	[DEC]	Proc	Risk Register (followed)	AM (followed)	Project management & business	Actions to take for the risk register	D
AW	For the flight test aircraft, it may not be available so … to meet our requirements… and hmmm the issue with the …	02:08:23	S							
JW	There's the dry bay definition	02:08:30	S							
BD	John's already got an action	02:08:34	S							
AW	… Smashing	02:08:41	F							
GW	Any more for risks?	02:08:44	Q	[EXP]	Proc					
NH	Is it worth thinking back on 320? See if there's a lessons learnt there that ought to be introduced as a risk here?	02:08:53	Q							
JW	It's one of the inputs we've identified … 320 lessons learnt document (…)	02:09:13	S							
GW	The risk is you actually need to get the lessons learnt document in time to actually use it	02:09:18	S							
GW	(…) that's all for the risks	02:09:31	Q							
PB	Where is the process defined … for reviewing the risks, what are you using?	02:09:40	Q	[CLA]	Proc			Project management & business	use of formal guidelines to establish the risk register	D
AW	This risk register sheet …I didn't know if there was …	02:09:50	S							
GW	It's about our RCPD process that we manage risks, it's part of the airbus UK policy that we manage risks	02:09:58	S							
PW	Absolutely, there's a definition on the 380	02:10:03	S	[INF]	Proc					
AW	Yeah is there's a document in there for risk management?	02:10:08	Q							
MD	… It's probably about 3 pages, the one I'm thinking of anyway. Which is the process, procedure of ensuring that they are reviewed and that they are handled …I can think of the one for 400M and that's only a couple of pages	02:10:27	S							
AW	Ok I'll try and get that	02:10:30	S							
MD	Either that or you need to put a few words I think, to say that the risks will be handled in this way.	02:10:36	S							
AW	Ok	02:10:39	F							
MD	Captured on the sheets, reviewed at…	02:10:44	S							
MD	See P.G.	02:10:50	S							
BD	[spelling out the name]	02:11:01	S							
AW	Ok smashing, thank you very much …sorry about that	02:11:10	S							
GW	Don't apologise, that's what we are here for! So final final call for risks …ok right, the next item is the agreement to proceed, but I think we will review the actions first	02:11:21	Q	[MAN]	Proc			Project management & business	Moving to the review of actions	P
AW	Yeah	02:11:22	A							
GW	Who would like to review the actions?	02:11:27	Q							
[…]	[…]= [Looking for biscuits!]	02:11:44								
NH	Right, all these actions are on Andy unless stated otherwise!	02:11:46	S	[DEC]	Proc	NH Notes	AM	Project management & business / Certification & testing / Systems design / Manufacturing and procurement	meeting management: review of actions to take and meeting closure.	P
NH	The actions from the equipment spec is to add the dry bays quantities or the reference to the quantities on paragraph 2.2.1, action on John Whines to confirm the new dry bay deletion requirements. We need to change the reference to ABD 0015 to refer to ABD 0100 for the intrinsic safety/	02:12:19	S							
BD	And intrinsic safety, I think these are separate issues …15 to 100 is a software change/	02:12:28	S	[DEB]	Ext					
NH	Change ABD 15 to 0100 and change the software from DO178A to DO178B …	02:12:40	S							
BD	But we're not talking about intrinsic safety though	02:12:42	Q							
MD	No intrinsic safety is a separate issue, I think there were two hardware issues to change, if there was a hardware change to work to DO160D and a new intrinsic safety/	02:12:55	S							
BD	Would be a new spec	02:12:56	S							
GW	You've gone in the specifics there and I think that from a more general point of view the action was to review the software section of the spec, ok?	02:13:12	Q	[MAN]	Proc					
NH	Ok review of the verification: I guess that that's the global thing to show that maturity is done, that the work is done at *Supplier* , to check for direct maintenance costs, changes and we need to define something. An action on John W. to ensure that the commercial agreement with Goodrich prevents the halting of production of the old unit until we are satisfied that it's appropriate. Back to andy's actions: check/	02:13:48	S	[EXP]	Proc					
TT	It's more the production capability rather than the actual production	02:13:52	S							
JW	Maybe both …	02:13:54	S							
NH	Right, to check with *Supplier* the probability of getting spurious alerts of cautions and then also to estimate ourselves the probability of getting spurious alerts of cautions and then to feed that back to chief engineer's office for a view on acceptability against the top level requirement to minimise them so it's those three actions	02:14:25	S							
JW	Are we not going to spell that out in the spec as well?	02:14:29	Q							
NH	… I don't know	02:14:36	A							
JW	I'll leave that to you	02:14:38	S							
NH	It depends how long it takes	02:14:39	S							
BD	I think we've chosen the threshold so I think that ball lies in our court rather than in the supplier's	02:14:44	S							
JW	Ok	02:14:45	F							

Speaker ID	Intervention	Time	I	Exch. role	Info type	Artefacts	Artefact type	Domain of competence	Topic Description	Topic origin
GW	Let's carry on with the actions anyway	02:14:47	S	[MAN]	proc	NH Notes (followed)	AM (followed)	Project management & business / Certification & testing / Systems design / Manufacturing and procurement (followed)	meeting management: review of actions to take and meeting closure.(followed)	P (followed)
NH	There's an editorial to change the phrase: more than one to two or more …ensure that *Supplier* will validate by model simulation the fuel leak detection implementation requirements. I think that was PFS requesting they modelled the requirements. Ah right the reference to the BS5501 which I think/	02:15:24	S	[CLA]	Ext					
MD	/That's the one for intrinsic safety	02:15:26	S							
NH	To apply the latest spec to any hardware changes. Review AP 1013 or GRESS document for applicability and there was an action on KM to check what level of GRESS is actually *Supplier* agreed to apply to this program.	02:15:48	S							
NH	Regarding the development plan, there's quite a few editorial changes, we need to check the/ find the mod number for the flight computer standard. Correct a mod number that was put in there for DMC and add a reference to the SDAC if that is a dependant system as well. Review the list of documents and whether they are appropriately split into input/output and others. Add the DDP approval dossier or and vendor documents will make it a specific list. And another aim to the validation section: to ensure the top level requirements are met completely and correctly. 4.2 The comment I've put is to put a more comprehensive statement, I think that's against *Supplier* 's validation actions, we need a much more definitive statement on that. The incorrect reference 5.5 and a verification plan requirement for *Supplier* including test readiness review and flight readiness review although I think those comments might not be appropriate to that document but just include them in the plan really, there's another section reference mistake. Add requirements review to the list of validation actions. Check AP2288 for the definitions of the reviews … the supplier v	02:17:52	S	[CLA]	Proc					
GW	And equipment	02:17:54	S							
NH	And equipment	02:17:56	S							
GW	Software equipment, system …	02:17:58	S							
NH	I picked up on the word Microsoft in that management plan, you didn't say if it was word, excel or MS project … We need to add verification plan from vendor as an input, we need to specify whether we are doing certification or flight testing, we need more detail required on the verification activities and define the maturity testing required by the supplier and a few editorial comments on the verification matrix. The document numbering needs to be addressed.	02:18:45	S	[INF]	Res					
NH	The certification plan: the action was to review ARP 4754 whether we really are going to apply it, change the phrase proved to assured by a process within the 178B and remove the sentence that referred to an unlikely hardware change. And regarding the risk review there was a new risk of change to the dry bay deletion requirements, we need to assess the problems associated with providing the RMI early and there's a new risk of not having an ACT capable aircraft for flight testing and you have an action to obtain some details of risk management processes from Paul G. and to add a statement to the risk register of how we are going to manage the process.	02:19:39	S							
GW	Anybody …	02:19:44	Q	[MAN]	Proc					
PB	About the sustainment of the risk register … for me it is sustained in the development plan, we are going to do a risk management process and this is how we are going to run it.	02:19:59	S	[CLA]	Proc					
GW	Did we miss any actions there at all?	02:20:03	Q	[MAN]	Proc					
GW	Right then, next item then is agreement to proceed … In terms of the requirements review we seem to have drifted in and out of preliminary design as well. That's a necessity to understand what the requirements are and what they are going to lead us to. I think generally we have a good view of what we are trying to do and where we are trying to get to. There are a few actions that need to be pursued to close off issues but from my point of view, I'm quite happy to continue with this development from now into the next phase of activity. So round the table then, agreement?	02:20:46	S							
GW	(…) Unfortunately since PS left we can't ask him if he was in agreement but we'll assume that he is in agreement and if you could make sure that he does not have any comments. And the minutes if they can be copied to people that were invited to attend but weren't able to participate for any reason so that they can be aware of the decisions that have been reached. Ok	02:21:26	S							
EH	Can I suggest that we have a review for the issue on the part B …	02:21:36	Q	[DEB]	Proc					
BD	Part A?	02:21:37	Q							
EH	Sorry I've got B on my brain, for part A because in the fact that's the requirements' go ahead and I think we do miss a trick actually and haven't actually got enough procedures today before we send formal specifications to the supplier, have we done everything? How should we do it?	02:22:02	Q							
PW	But we reviewed the part a today, it's only the additional stuff/	02:22:10	S							
EH	/oh sure any change (…) we've done most of the design review in a way, but I think formerly we should say: yes that is now satisfactory to go so we are talking about 2 or 3 experts and the people that are involved in the process to ensure that yes definitely we've covered everything.	02:22:46	S							
AW	Is that not captured by the signatures? Basically if they don't sign it that means they are not happy to send it …they shouldn't have signed it in the first place.	02:22:58	Q							
GW	That's what their goal is, when PFS is asked to approve that document he should be contacting each of these specialist areas and making sure they are happy with the contents in that spec, now whether he does that by calling a review and getting everybody in a room and saying I agree or I have issues or whether it's by going around visiting each individual it's down to hi really isn't it? How he wants to approach it … I think we need to recognise that something needs to be done and there's a couple of options, but perhaps you can raise it with/	02:23:40	S	[DEC]	Proc					
EH	/You're right it's up to him to decide how to cover it, it's his call.	02:23:43	S							
GW	As an authoriser, I do look to the approver as the person that makes sure that everything in the document, whatever it is, is correct and complete, and I'm just adding on to say that it's applicable to the project.	02:24:10	S							
GW	Ok, in terms of requirements review then I think we are finished.	02:24:14	S							

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APPENDIX B

RESULTS FROM THE TRANSCRIPT CODING OF THE AIRBUS UK REQUIREMENT REVIEW

This appendix presents the tables of results based on the transcript coding of the Airbus UK Requirement Review. These tables were used to build the graphs presented in chapter 5. The various tables have been grouped in 4 sections: intervention coding results, exchange roles coding results, information type coding results, and topic coding results.

1. TABLES OF RESULTS FOR THE INTERVENTION CODING

Overall intervention coding results		
Intervention type	**No.**	**%**
Statements	459	57%
Questions	211	26%
Answer	101	13%
Feeling	32	4%

Speech time per role		
Roles	**Time**	**% (time)**
Chief Engineer's office (Chair)	00:54:15	40%
Single Aisle Fuel Systems Avionics (secretary)	00:23:05	17%
Single Aisle Fuel Systems Avionics	00:11:32	9%
Single Aisle Fuel Systems Team leader (action taker)	00:10:28	8%
CPD team leader	00:06:05	4%
Quality Management for Systems and Software Assurance	00:01:49	1%
Head of Control / HMI department	00:08:53	7%
AUK Airworthiness	00:03:04	2%
Procurement Fuel Commodity	00:01:04	1%
Software Assurance	00:03:18	2%
Fuel Systems Safety and Reliability	00:08:53	7%
Hardware Assurance	00:03:13	2%
Total	02:15:39	100%

Speech time per meeting role	
Meeting roles	**% time**
Review team	15%
Chair	40%
Project team	19%
Secretary	17%
Action taker	9%

Review team composition		
Roles	**Time**	**% (time)**
Chief Engineer's office (Chair)	00:54:15	40%
Quality Management for Systems and Software Assurance	00:01:49	1%
Head of Control / HMI department	00:08:53	7%
AUK Airworthiness	00:03:04	2%
Software Assurance	00:03:18	2%
Hardware Assurance	00:03:13	2%
Rest of review team	0:20:17	15%

Project team composition		
Roles	**Time**	**% (time)**
Single Aisle Fuel Systems Avionics (Secretary)	00:23:05	17%
Single Aisle Fuel Systems Avionics (action taker)	00:11:32	9%
Single Aisle Fuel Systems Team leader (Action taker)	00:10:28	8%
CPD team leader	00:06:05	4%
Procurement Fuel Commodity	00:01:04	1%
Fuel Systems Safety and Reliability	00:08:53	6%
Rest of project team	00:38:02	19%

2. TABLES OF RESULTS FOR THE EXCHANGE ROLES CODING

Exchange Roles - Overall results				
Category	**Time**	**%**	**No. of exchanges**	**Time per exchange**
Exploring	00:34:58	24%	27	00:01:18
Clarifying	00:33:15	23%	40	00:00:50
Debating	00:20:42	14%	13	00:01:36
Evaluating	00:13:09	9%	12	00:01:06
Decision Making	00:11:59	8%	19	00:00:38
Managing	00:09:30	7%	12	00:00:48
Informing	00:09:19	6%	13	00:00:43
Resolving problems	00:08:48	6%	8	00:01:06
Digressing	00:01:42	1%	6	00:00:17

Evolution of exchange roles during the meeting									
Time split	**00:00:00 to 00:49:37**			**00:49:37 to 01:36:42**			**01:36:42 to 02:24:14**		
Category	**No Exch.**	**Time**	**% (time)**	**No Exch.**	**Time**	**% (time)**	**No Exch.**	**Time**	**% (time)**
Exploring	12	00:15:45	32%	9	00:12:22	27%	6	00:06:51	14%
Clarifying	19	00:14:48	30%	13	00:10:44	23%	8	00:07:43	16%
Debating	2	00:03:37	7%	7	00:10:32	23%	4	00:06:33	14%
Evaluating	0	00:00:00	0%	2	00:03:38	8%	10	00:09:31	20%
Decision Making	6	00:04:04	8%	3	00:02:11	5%	10	00:05:44	12%
Managing	3	00:04:42	10%	3	00:01:24	3%	6	00:03:24	7%
Informing	4	00:03:02	6%	3	00:01:15	3%	6	00:05:02	11%
Resolving problems	3	00:03:22	7%	3	00:02:50	6%	2	00:02:36	5%
Digressing	0	00:00:00	0%	2	00:01:34	3%	1	00:00:08	0%

Intervention type and Exchange roles								
Exchange role category	**No. Statements**	**% S**	**No. Questions**	**%Q**	**No. Answers**	**%A**	**No. Feelings**	**%F**
Exploring	115	58%	53	27%	24	12%	6	3%
Clarifying	105	53%	58	29%	29	15%	5	3%
Debating	66	61%	32	29%	9	8%	2	2%
Evaluating	43	61%	16	23%	6	8%	6	8%
Decision Making	38	54%	17	24%	9	13%	7	10%
Managing	25	45%	19	35%	10	18%	1	2%
Informing	33	62%	12	23%	7	13%	1	2%
Resolving problems	29	64%	7	16%	7	16%	2	4%
Digressing	-	-	-	-	-	-	-	-

3. TABLES OF RESULTS FOR THE INFORMATION TYPE CODING

Overall information type timing			
Information type	**No Exchanges**	**Time**	**% (time)**
Process Info	95	01:20:53	57%
Product Info	16	00:19:50	14%
Resources Info	6	00:07:21	5%
External Factors Info	28	00:34:40	24%

Evolution of information type during the meeting									
Time split	**00:00:00 to 00:49:37**			**00:49:37 to 01:36:42**			**01:36:42 to 02:24:14**		
Information type	**No Exch.**	**Time**	**% (time)**	**No Exch.**	**Time**	**% (time)**	**No Exch.**	**Time**	**% (time)**
Process Information	28	00:22:16	45%	30	00:27:54	61%	37	00:30:43	65%
Product Information	8	00:10:56	22%	6	00:08:09	18%	2	00:00:45	2%
Resources Information	0	00:00:00	0%	0	00:00:00	0%	6	00:07:21	16%
External Factors Information	13	00:16:08	33%	8	00:09:57	22%	7	00:08:35	18%

Exchange roles and information types				
	Information types			
Exchange roles	**Process Info**	**Product Info**	**Resources Info**	**External Factors Info**
Exploring	37%	31%	0%	32%
Clarifying	60%	12%	8%	20%
Debating	74%	5%	0%	21%
Evaluating	43%	21%	11%	25%
Decision making	81%	0%	2%	17%
Managing	100%	0%	0%	0%
Informing	40%	14%	18%	28%
Resolving problems	40%	0%	13%	47%

4. TABLES OF RESULTS FOR THE TOPIC CODING

Domain of competence timing		
Domain of competence	**Time**	**% (time)**
Project management and business	01:13:28	38%
Certification and testing	00:52:38	27%
Systems design	00:35:29	18%
Manufacturing and procurement	00:19:48	10%
Aircraft configuration and architecture	00:13:13	7%

Overall topic origin timing	
Origin type	**% (time)**
Predetermined	69%
Derived	24%
Unexpected	6%

APPENDIX C

FULL TRANSCRIPT AND CODING OF THE AIRBUS UK PRELIMINARY DESIGN REVIEW

This appendix presents the full transcript and coding of the Airbus UK Preliminary Design Review recorded and observed by the author at Filton (Bristol, UK) in November 2003.

Reminder of the coding conventions for the TCS:

Name of column in TCS	**Coding criterion**	**Coding elements (with shorthand conventions used in TCS)**
1	Intervention type	Statement (S), question (Q), answer (A), or feeling/emotion (F)
Exch. role	Exchange role	Informing (INF), exploring (EXP), resolving problems (RES), managing (MAN), evaluating (EVA), debating (DEB), digressing (DIG), clarifying (CLA), or decision making (DEC)
Info type	Information type	Product (Prod.), process (Proc.), resources (Res.), or external factors (Ext.)
Artefact type	Artefact type	Office (O), Drawing (D), Activity management (AM), Information management (IM), Calculation (Ca), Communication (Co), Component (C), or Testing (T)
Topic origin	Origin of the discussed topic	Predetermined (P), derived (D), or unexpected (U)

Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
DW	Who's agreed to do minutes?	00:00:15	Q	[MAN]	Proc	DW+RF presentation overheads	AM	project management & business	organising chair and secretary	P
JL	I'll write them down	00:00:19	A							
RF	… At least you can't write yourself down as an actionee!	00:00:22	S	[DIG]	-					
DW	… Right then, we're all ready to go, shall we kick off?	00:00:30	Q	[MAN]	Proc					
DW	… Right, good morning, this is the PDR for the trim tank pump. I've agreed to chair the meeting and I've put out the agenda on a slide there, but all that's the same as what RF said previously… it's worth going round the table to remind TS who everybody is and what they deal with in the company… so I'm DW from the chief engineer's office…	00:01:20	S							
GW	… I'm GW, materials and processes (…)	00:01:32	S	[MAN]	Proc			project management & business	presentation of the participants	P
TS	I'm TS, I'm chide engineer of the fuel team at the Nichols Airborne (…)	00:01:54	S							
RF	I'm RF, assistant systems engineer (…)	00:02:07	S							
JL	I'm JL, team leader (…)	00:02:13	S							
IB	I'm IB, procurement, quality and security for supply chain development …	00:02:20	S							
LR	LR, fuel tank specialist, DCS …	00:02:29	S							
GH	GH, fuel systems safety	00:02:33	S							
[…]	[…]	00:03:00	-							
DW	Another slide just to remind people of the purpose of today, it's, err, TS to present the design concepts and manufacturing schedule to solve the in service problem with the trim tank pump and the objective of this review is to review the proposed designs and schedule to give TS authorisation to go further in the development … is everybody happy with the background of why there was a problem with the trim pump?	00:03:32	Q					project management & business	presenting the meeting artefacts	P
DW	Do we need to go through that with everybody? Or	00:03:36	Q							
TS	I've actually got a couple of slides in my presentation …	00:03:37	S							
DW	Oh, ok that will be fine then … I think most probably most people have been internally involved and have some background	00:03:50	S							
DW	… Ok so do you want to go directly into your slides then TS?	00:03:58	Q							
TS	Yes …	00:03:59	A							
[…]	[…]=[Preparation of handouts]	00:04:35	-							
TS	I'm gonna pass around hard copies of the presentation …	00:04:37	S							
[…]	[…]=[Passing around the handouts]	00:05:33	-							
TS	So I've just passed around hard copies of the presentation and I also brought along a third report, last one asked by AUK and I also have an updated EDES document, … I'll hand these to RF	00:06:15	S							
TS	… One other thing for the purpose of illustrating some of the points I'll make this morning. I brought along hardware to illustrate the configuration. This isn't the exact model, it's just something to illustrate before and after… the thrust washer and the pin … it's something to avoid that my luggage gets delayed getting through … err, it's amazing how thorough they are …	00:07:08	S			Rotor assembly	C			
TS	So, err, I've got a pin and a thrust washer on the new design and this rotor has had a rework also. This will probably get passed around … Ok, so we've already talked about the agenda and again this is a good opportunity to talk face to face about specific issues, any of the questions that come up that we've covered in our report, hmm, hopefully we'll answer all the questions…	00:08:04	S							
TS	So, I'll go through briefly again to the background, the cause of failure and correction, the design change, I've got a slide on the proposed qualification and then the recovery schedule … I'd like to leave here with either the authorisation to go ahead with the design or a very specific action …	00:08:39	S			Parker presentation, slides 1-13	AM/D/T/Ca			

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Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
[TS]	[...]=[Presentation]	00:21:58	S	[INF]	Prod	Parker presentation, slide 14 +	D/C	Systems design	presentation of the new pin design by the supplier	P
TS	On this diagram, what we are looking at is a rotor assembly, the same as this shaft here and it was done by design engineering so you have all the loads that are applied to the shaft ...	00:22:21	S							
[TS]	[...]=[Presentation]	00:35:17	S			Parker presentation, slides 15-18	Ca/D			
TS	... Ok, this chart summarises the design changes on page 18 ... ok, I'll start with the pin ...	00:35:49	S			Parker presentation, slide 19	Co/Ca			
[TS]	[...]=[Presentation]	00:36:58	S							
RF	Does that combine the diameter change and the length? ...	00:37:02	Q	[CLA]	Prod			Systems design	dimension changes to the pin	P
TS	No that's just one, each of these is just changes made at that level, down the bottom here, we have what all thee things mean ...	00:37:12	S							
[TS]	[...]=[Presentation]	00:40:21	S	[INF]	Prod			Systems design	presentation of the new pin design by the supplier	P
LR	Question then, how are you selecting these changes? Is it just to show the trend in the stresses? I mean why change the string of sets, when clearances diagram should have shown a much thicker change, to reduce the loads even further, so how are you selecting the changes we are looking at?	00:40:44	Q	[CLA]	Proc			Systems design	dimension changes to the pin and effects	P
TS	Hmm, well it's back on the impeller, hmm, specifically on the labyrinth seal clearance, we went through a stack of set to see what you could hold that clearance to ... to be absolutely sure that it would never contact under worst case tolerance conditions, that's how we went to the 0.007 - 0.0095 clearance	00:41:16	S							
LR	Indeed you could have 0.009 ...	00:41:19	S							
TS	Well, err ... there would be a risk of tightness problem and anything higher we would have been forced to higher our positional tolerances ... so we started off with a stack of analysis on the impeller, then we looked at the number of bleed holes ... first of all, err, we didn't want to make a change that would modify the circulation flow ... on this curve here we are also showing our estimated leakage flow, we didn't want to change that pressure because we know that dead head pressure rise on a (...) it's very hard to meet the original specification requirements, so we didn't want to make significant change on performance, so again we didn't want to make change to the (...) so we had 3 holes originally, that went to 6, and I have another curve to show, and it brought us a slightly bigger clearance and that brought a significant reduction on load without risking to change performance ...	00:43:34	S							
LR	These changes haven't had a knock on effect on the tolerances?	00:43:42	Q	[CLA]	Prod					
TS	That's right that's right, I think the only tolerance change we've made, let me show you our drawings, we did add, err, paralleloid part at the bottom of our slot on the thrust washer ... previously (...)	00:44:11	S							
TS	Hmmm, ok, so, the current changes, and I do have a curve to show you, on the thrust washer basically ... a couple of changes including the slot length and radius slot (...) and another thing I talked of, the slot bottom (...)	00:44:54	S	[INF]	Prod					
TS	On our rotor, we had to increase the size of the hole to accommodate the new pin and we have a thru hole in the centre to maintain a cooling flow	00:45:59	S							
RF	What sort of diameter (...)?	00:46:05	Q	[CLA]	Prod					
[...]	*[...]=[Can't understand the audio]*	00:46:42	-							
TS	So nominally, all these changes mean that the bending stress has moved in 16% of the old value ... and with the pin off centre 12% ...	00:47:08	S							
GW	How far does that off centre ... gets ... goes off centre? Does it go off centre by the amount you estimated on the failed one ...	00:47:19	Q	[EVA]	Prod			Systems design	movement of the pin in the assembly	P
TS	Oh, it can't go that far ... I think we only have about 10000, 10 or 15 000 cycles	00:47:29	A							
GW	I mean the old one in comparison, do you allow it to move to the exterior of the thrust washer, is that what that point 5 of the representative new one versus an old pin offset ... so it virtually touches the outside of the washer ... was that typical of the one that failed?	00:47:51	Q							
TS	The one that failed was off centre and hum, when we ran our 8000 hours endurance test in our lab on 2 different units, it was also obvious that pins (...) it's unfortunate that we didn't hang on to the change at the time (...)	00:49:04	S							

Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
TS	Another point of discussion in our report is that when we ran our endurance tests we did, hmm, full cycles, some shut off cycles and some dry runs (...)	00 49 36	S	[INF]	Prod			Certification & testing	test run results for new design	P
TS	OK, so on the thrust load with the new impeller seal clearances and 6 holes, it brings us in this range here 7 and 9 and a half thousandth and the load reaches just under 60 pounds, that's where we get the reduction of force acting on the thrust washer	00 50 08	S							
[TS]	[...]=[Presentation]	00 53 28	S			Parker slide presentation, slides 20-21	Co/Ca			
TS	Let me walk you through this curve, we are showing pressure rise and overall efficiency on the vertical axis and fuel flow in miles per hour ... let's talk about pressure rise first, the dotted deadline represents the minimum pressure that can test to (...), this line here represents a same unit, we took one test unit to test it with a baseline impeller ... there's the pressure rise with flow, the baseline impeller (...) we feel that's an acceptable change, we also have a 30 PSI maximum (...)	00 54 42	S			Added slide showing graph	Ca			
RF	So your thrust load calculations were based on 30 PSI?	00 54 46	Q	[CLA]	Proc			Certification & testing	test run on the new component	P
TS	That's right ... and again if we go cold, this is all done at basically room temperature, if we go cold (...)	00 55 30	A							
TS	As far as the input current (...) we have a maximum level of 3.3 amps and it dropped down to a tenth of an amp (...) and the overall efficiency (...)	00 56 40	S							
[TS]	[...]=[Can't understand the audio]	00 57 10								
LR	Sorry, the bottom line of the flow, is that the simulated bleed to the jet pumps?	00 57 16	Q	[EXP]	Proc					
TS	Yes, well they are, the flow to the jet pumps is in addition to this	00 57 23	A							
LR	So when you show zero, the status of flow through the pump reaches the injector?	00 57 29	Q							
TS	Yes there is still the injector ... I can't remember how much that is, I think it's less than (...)	00 57 47	A							
LR	So, you've got a limit of 30 PSI ... so you're going to exceed that, aren't you?	00 57 57	Q							
TS	30 PSI is applied at 18p which is our peak condition, I guess I'd have to go back to the spec to see what (...) we impose a 30 PSI max temperature ... I think there should be a margin between that and pressure for cold temperatures ... I can double check that ...	00 58 42	A							
LR	So that test was run with the new impeller ... it wasn't an attempt to get max clearance, min clearance? ...	00 58 58	Q	[CLA]	Proc					
TS	I don't know, I think we're at nominal, she should be at nominal clearance, it wasn't intended to measure the flexibility of the system (...)	00 59 46	A							
TS	We started with this released hardware, this is a reschedule hardware, we risk released just the parts that we needed that were different: the pins, the thrust washers and the impellers ... these are in accordance with the EDES ...	00 60 30	S	[DEB]	Proc	Parker slide presentation, slide 22	AM	project management & business	changed parts and timescales for supplier	D
RF	Is there an in service part? ...	00 60 34	Q							
TS	... Well the ...	00 60 49	S							
LR	That's a procurement issue ...	00 60 55	S							
JL	What we had is that you'll have the parts, all the new parts by the 12th ...	00 61 01	S	[EXP]	Proc					
TS	We'll have the replacement parts that have changed by the 12th and we are building units right now, during January February March, that's the next stage ... and the bottom part of the schedule is the recommended phase-in, there's some flexibility in there, we've taken in consideration that we'll have these replacement parts in the summer (...) so in this particular schedule it shows that the first kit will be shipped by March	00 62 15	S							
JL	So that's to ship ...	00 62 18	Q							
TS	Ship first kit ...	00 62 19	A							
[TS]	[...]=[Can't hear much]	00 63 16	S							
JL	When would you have you're first pump ready for testing? ...	00 63 21	Q	[CLA]	Proc			Certification & testing	pump testing by supplier	D
TS	Hum, in the late June	00 63 27	A							
JL	And when you put 'our approval' then, what approval are you asking for then? Because I don't think we'd want to approve a change like that without any testing ...	00 63 37	Q	[CLA]	Proc					
TS	Oh, ok ... this testing is a machinery testing ... so the test you're talking about is a qualification testing	00 63 54	Q							
JL	Yeah	00 63 55	A							
TS	... Hum, well let's talk about that, on the pin design change ... we did some analysis ... but testing is not that simple ... the reason that's a tough question, is that we didn't really do 7000 hours out of the previous ... maybe the hmmm, yes sorry	00 64 39	S							
JL	It's going back to your old design, do you feel that if you hadn't taken the units apart you would have got a failure on the other design?	00 64 45	Q	[EXP]	Proc			Certification & testing	identification of design failure by the supplier	D
TS	Well not necessarily, again hmm, if hmm, because once you get a wear due to stresses on the exterior (...) even then I can't say for sure ...	00 65 07	A							
JL	(...) I know you said before you were prepared to run that test again, are you behind that qualification? Am I correct?	00 65 28	Q	[RES]	Proc			Certification & testing	qualification of the new design by supplier	D
TS	Yes you are, well, hmm, I, we were assuming that you guys, that Airbus would accept nothing less than testing!	00 65 35	A							
JL	I would definitely want that test done, in my opinion	00 65 40	S							
TS	... I think in this case, we would want, obviously we would want to handle that very carefully, on behalf of absence of any limitations on the contact parts and on high stress parts	00 66 00	S							
JL	At what point did you get your first evidence of wear?	00 66 03	Q	[INF]	Prod					
TS	I think, hum, if we go back to the original endurance test, this was taken apart after 2000 hours, once they saw the wearing, it might have been 1000 (...) we have that information I just don't have it here with me	00 66 42	A							
[...]	*[...]=[Can't understand the audio]*	00 67 45	-	-	-					
LR	Well, what test are we talking about now?	00 67 47	Q	[CLA]	Proc					
TS	We would have to run, we would have to pick a condition that gave us maximum thrust load ...	00 67 55	S							
[...]	*[...]=[Can't understand the audio]*	00 75 05	-	-	-					

Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
JL	Isn't there any concern that there will be a huge change in the load conditions for the new design ...	00 75 16	Q	[DEB]	Ext					
TS	Can you repeat that please?	00 75 18	Q							
JL	You were talking about making a more harsh test, the one on the new units ... if you change your load conditions, the new unit won't be comparable to the old unit, and they won't be verified, well not directly	00 75 31	Q							
TS	That's right ...	00 75 33	A							
JL	Ideally they should be compared in the same conditions ...	00 75 41	S							
[...]	[...]=[Nothing said]	00 76 30	-							
TS	I think hmm ... I think I can ask ... I can ask for that data (...)	00 77 06	S							
[...]	[...]=[Can't understand the audio]	00 78 32	-	-	-					
TS	On the original design, I'm sure that we did a, we did an early disassembly and we had 4000 hours, that's the initial time and we started tracking the problem ... it's only been 400 hours, that's the only thing I can say for sure (...)	00 79 04	S	[INF]	Proc					
GW	... I mean we are talking about deformations opposed to ...	00 79 09	Q	[DEB]	Prod			Systems design	deformations on the old design	P
TS	... Hmm ... yes we probably are talking about deformation	00 79 17	A							
GW	So if we go back to your graph, according to that quick drop off you get that deformation very very quickly indeed	00 79 25	S							
TS	No, no that deformation there, that's not even ... I'm talking about indentations, visual indentations at the surface of the thrust washer and ...	00 79 39	S							
GW	So a hammering type	00 79 41	Q							
TS	Yes a hammering or peening type, that's what we wanted to show here ...	00 79 50	A							
[...]	*[...]=[Can't understand the audio]*	00 82 53	-	-	-					
TS	The last, the last slide I had was just an updated Weibull analysis ...	00 83 02	S	[INF]	Prod	Parker slide presentation, slide 23	Ca	Systems design	movement of the pin in the assembly	P
[TS]	[TS]=[Slide presentation]	00 87 58	S							
GW	And does the pin tend to stay in its installed position in the rotor shaft or does the pin try and rotate within the rotor shaft?	00 88 06	Q	[EXP]	Prod					
TS	I believe that once the pin, if it's offset just a little bit it will stay in that position ... it shouldn't move ... I guess you could argue that the thrust washer forces the pin to stay in that position ...	00 88 24	S							
[...]	[...]=[Interruption]	00 89 25	-	-	-					
LR	This pin is now the same diameter as the one at the top of the rotor	00 89 28	Q	[CLA]	Prod			Systems design	use of pin in assembly	P
TS	That's correct, and we plan on using the same pin on both of them (...)	00 89 42	A							
LR	What type of ... wearing, rubbing would you expect on that?	00 89 50	Q	[CLA]	Prod			Manufacturing & procurement	dimension and tolerances of the new parts	D
TS	Well, this pin, the only function it does is to make sure that the thrust washer spins with its shaft, the only loading on that pin would be the torque on that thrust washer and that thrust washer only functions as a bumper during start up and so that's a very lightly loaded pin ...	00 90 21	S							
LR	The pin and the hole diameter clearances are the same now that you are planning to use that thrust washer? ...	00 90 29	Q	[RES]	Prod & Proc					
TS	You know, I hope so ...	00 90 36	A							
GW	I think there's a possibility of interference hmmm ...	00 90 40	S							
TS	Yeah, we answer that in our response, we've used these fits before and occasionally the pin remains tight so that's a problem for us to solve. In fact at one time we said we should put a light press up for the pin ... but we decided against it, well we could have but it remains very difficult with a very light press ... what's that?	00 91 32	S							
GW	Grease?	00 91 33	Q							
TS	Well, no the pin is so small it doesn't really help, they have to apply a little press ...	00 91 44	A							
IB	So what's the logic of using a more robust pin in the no thrust condition, when the loads appear in the high thrust?	00 91 52	Q	[CLA]	Proc			Systems design	use of a more robust pin	D
TS	Well, there was no logic there, ha-ha, it was a hmm ... that's a good question hmmm, I hate to give you this answer but unfortunately the design of the thrust washer and the pin arrangement here, unfortunately was carried over for another design and although we've never had problems with the design it doesn't seem to go near enough hours as foreseen ... so hmm we've learnt our lesson here that legacy designs aren't always acceptable ... very important painful lesson ... I think in this case here we had certain diameters and bearing elements (...) At this end down here, part of it was legacy same bearing, same thrust washer ...	00 93 34	S							

Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
GW	The pin itself has a material change, it's currently the ...	00:93:40	S	[CLA]	Prod			Systems design	Material used for the pin	P
TS	Well, sorry, we will change that also, that pin doesn't carry any load	00:93:45	S							
GW	I understand, it's not currently 13-8 then?	00:93:48	Q							
TS	That's right, it's a standard MS I believe it's the same 410 or 416 ...	00:94:01	A							
GW	And the other pin is not a spherically ended pin?	00:94:04	Q	[CLA]	Prod					
TS	Hmm, no, it is not	00:94:08	A							
GW	So it's just ... it's the only similarity is the diameter of the pin	00:94:12	Q							
TS	That's right ...	00:94:16	A							
RF	What material did you say earlier?	00:94:20	Q	[EXP]	Prod					
TS	416	00:94:21	A							
RF	Is that a ... do you have reservations to that particular material?	00:94:26	Q							
[...]	[...]–[whispers and overlap]	00:94:53	-	[DEB]	Prod					
TS	I think that another issue is that hmm ... when we went back to some of the earlier analysis ... the thrust loads in the worst case where higher than what we'd expected and that's why we really pushed for a change	00:95:22	S	[DEB]	Proc					
GW	Does that mean that that's genuine because if we back up to the number, to the speed at which we accumulate dust, we'd expect failures in a very very short time, perhaps 2 fold of the magnitude chart that you've got here !	00:95:40	S							
TS	That's right but, but ... the hmm ... I guess we'd loose in thrust load and still hold those stresses ...	00:95:58	S							
TS	That was a ... I think those were all the slides I had for this particular presentation ... I believe the major open issues at this time are the ... defining of a test plan that is acceptable ... we need to consider the length of that test plan I guess the question I have is: does it seem reasonable to expect a preliminary approval of the change to allow us to forward a full testing?	00:96:47	Q	[EVA]	Ext			Certification & testing	defining a test plan	D
IB	The CDR will give / the full ...	00:96:50	A							
JL	/ yeah but yeah but / you're at QTP ... we can only end up pushing the program/	00:97:02	S							
IB	/ that's right, sure exactly	00:97:03	S							
JL	... I would like to see some testing first to begin with	00:97:12	S							
RF	... A side by side comparison ...	00:97:23	S							
LR	(...) why did you make the assumption, changes, dynamics, how it behaves ... because if you present a test like you just showed us where the initial conditions changes slightly, we are back to where we were at square 1. A real partnership between us would be telling us the primary conditions and the rationale why you selected these conditions	00:97:57	S							
LR	... it's their design	00:98:03	S							
TS	Well ... frankly ... personally, we feel that the ... worst case would be the low flow in high pressure conditions, I think you saw on our curve the ... yeah about 30 PSI at shut off (...) so low flows will give you the highest thrust and our bearing, that load is always central, and the load applied to the thrust washer is always off centre (...) the concern would be ... the concern would be where we would have a load condition where the thrust washer was off centre by the maximum (...) from an analysis standpoint we are sure that we will eliminate the potential stress failure (...)	00:100:16	S							
GW	Is that genuinely a problem because presumably the fatigue cracking was diametrally opposite? That damage on the rotor side ...	00:100:35	Q	[DEB]	Prod			Systems design	Impact on stresses/fatigue/failure	D
TS	I understand that but the thrust washer is still applying a load on the pin on top of that	00:100:45	S							
GW	Is that generally a problem?	00:100:47	Q							
TS	Hmm, well I think originally, the first conception was (...) but we feel that these high contact stresses and the deformations that occurred and the stress concentration factors may have tormented ...	00:100:54	S							
GW	Sure they are diametrally opposite that's why I was asking whether you think the pin rotates within the shaft, that it spins if you like within the rotor shaft because if you've got that configuration then you rotated that damage so that it was coincident with the bending stress	00:101:43	S	[DEB]	Proc					
TS	I don't think ...	00:101:46	S							
GW	... I find it difficult to see how it's an issue with that dimension ...	00:101:55	S							
TS	I think it's an issue of fatigue ... we don't know this ...	00:102:01	S							
GW	Well what would it / (...)/	00:102:06	Q							
TS	/ It does reduce / the a ... although slightly, it does reduce the cross section / of the	00:102:13	S							
GW	Yes, so you're saying that increases the maximum bending stress? ... it's like putting a notch on the other side / in effect /	00:102:23	Q							
TS	/ That's right / but we are also getting a ... there are still high contact stress on the opposite end, it's not all deformation on one side, the thrust washer is applying a high load ... I understand what you are saying: crack initiation, higher stress loads ...	00:102:51	S							
GW	That was the case in the failure	00:102:54	Q							
TS	That's right	00:102:55	A							
GW	It just strikes me that looking at deformations as a criteria seems quite irrelevant ...	00:103:04	S							
TS	Well I think that's why we felt that when we summarise our analysis here everything's done according to bending stress because that's ultimately the failure ...	00:103:26	S							
GW	And what about the failure analysis? Was there any evidence of other smaller fatigue cracks (...)	00:103:36	Q	[CLA]	Prod					
TS	No, no ...	00:103:39	A							

Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
[...]	[...]=[coffee break GW and TS still talking about stresses in background]	00:108:16	-	[DIG]	-	Playing around with the assembly parts	C		-	
TS	So I would like to check a question that GW asked earlier and that was hmm ... again the question was whether it was possible that the pin could shift in the original design, with 2 different types of motions sliding and rotating We've never seen any evidence that the pin could rotate ... I guess it is possible	00:109:17	S	[RES]	Prod			Systems design	movement of the pin	D
[...]	[...]=[noise RF returning coffee]	00:109:59	-	-	-				-	
RF	So, where are we now?	00:110:00	Q	[INF]	Proc			project management & business	precision on documentation	D
TS	Yeah I guess we are still in discussion, questions, comments or concerns	00:110:05	A							
TS	... Did I mention I brought an updated FMEA list, you'll be getting an electronic, you should be getting it today and I have a hard copy here of the updated list, the updated EDES and separate documents in response to the specific questions ...	00:110:42	S							
JL	... I've got a few actions down, basically I'll read through them and if there's anything else that you see ... hmm action one return what you believe are appropriate endurance testing with support from the earlier design producing a comparison and hmm I'd like to see a revised schedule, some idea of when you think you can start this testing, how long it would take us to get ... sort of number of hours ... I think it's going to be crucial if we want to move forward	00:111:34	S	[DEC]	Proc			project management & business	requirements for next design review	P
TS	Yeah	00:111:35	F							
DW	I think in particular as well, JL touched it earlier, item number 13 on your schedule there receiving AUK approval for December, I guess the question is what level of approval are we looking at there? ... As JL said we would expect to be seeing some sort of testing that's done maybe ahead of a CDR, some formal testing post CDR and at some point after that then we'll give you effectively the instruction to go ahead and say yeah we are happy with those changes, testing approved and results looks good and then you can kick off production from there ... now obviously that 5th December looks rather tight to do all that / That's right /	00:112:41	S							
TS	/ Well that's before we /	00:112:41	S							
JL	/What you need / we probably wouldn't get an EDES signed	00:112:44	S							
DW	No I don't think so	00:112:45	S							
JL	The other problem would be your DDP ...	00:112:52	S	[DEC]	Proc					
TS	I think we need the formal approval before we can ship the units (...)	00:113:18	S							
DW	Yeah that's right, that's one way of looking at the issue, is to say this is the program to build units at risk ... because it doesn't quite tie with maybe what we are expecting in terms of the next months in terms of CDR expectations etc ... / I think we need more detail schedule /	00:113:46	S							
JL	/ I think I'd like to see/ something as in what you think you can do and what testing you can do and we need to discuss / round /	00:113:51	S							
DW	/ Yeah I think that's / probably best (...)	00:113:52	S							
JL	The further issue is it's got a 5000 hours limitation	00:114:04	S	[CLA]	Ext			Certification & testing	endurance testing limitations	D
[...]	[...]=[coughs and low voices talking about the 5000 hours issue at AUK, some aircrafts have gone passed that life]	00:115:05	-							
DW	We'll be having a discussion this afternoon about the corrosion issue, which was the issue that was keeping 5000 hours up there, RF has scheduled a meeting this afternoon to discuss that	00:115:18	S							
[...]	[...]=[multiple conversations about the 5000 hours]	00:116:30	-							
LR	Is that what's driving this March date? (...)=(interruption)	00:116:53	Q	[CLA]	Ext					
JL	... So the 5000 hours is driving the March date, now that you've said that we don't need the safety issue that would require a longer run, I think you're gonna have to resolve the 5000 hours because we've got a very clear position in fuel//	00:117:09	S							
LR	/It would be a shame to compromise what you're doing/	00:117:12	S							
TS	//Oh yeah that's right (...)	00:117:20	F							
LR	If this pin hadn't been found broken, what would be the cascade of events? A broken pin, floating about, the rotor would have been carrying on working ...	00:117:36	Q	[EXP]	Proc			In service & Certification and testing	detection of broken pin by the supplier	D
TS	What we found in our testing in the lab is that people with a broken pin ... the pin is trapped somewhat and hmm under some conditions it won't make any difference, you'll never know that the pin is broken, except that the other half of the pin is carrying all the thrust load and ultimately, depending on how that stress is distributed	00:118:05	S							
[...]	[...]=[people eating, paper noise, coughing]	00:	-	-	-			-	-	-
TS	Recently we issued a letter on the issue of the state of corrosion and we'll talk about that this afternoon We've seen 2 units that were returned from the field with some evidence of corrosion on the inside of the stator and on some of the other units that have come back there was also evidence of corrosion and on this particular unit that came back with a failed pin there was evidence of corrosion on the stator at around 4000 hours, so ... hmm, we have made some improvements to the technical and quality side of things and there's some additional improvements that we are trying out ... in the mean time the issue in the letter of the 5000 hours limitation be lifted (...)	00:121:35	S	[DEB]	Ext			Certification & testing	Safety linked to corrosion problems	P
JL	My questions on that would be the same what are the implications ... in terms of safety, and are you committing to any performance issues?	00:121:46	Q							
[...]	*[...]=[Can't follow the thread of the audio]*	00:123:57	-	-	-					

Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
TS	Let me add another comment here, early on when this problem was first identified, the best we could do or at least the best we thought we could do was a nickel plate lamination and hmm, I brought some tests results that we did on a sample stator and unfortunately our dry-run part consumption had a huge impact on performance so we've a … we've discounted that option because it would have taken us outside the specification requirements … if I recall, in the … in the early design dry-run part consumption was a key design variable (…)	00:125:06	S	[INF]	Prod			Systems design	Corrosion on stator	P
TS	So when we look at the stators that have run through the corrosion test … the testing that we've done was a cold cycle at -40F and hmm bring it back to room temperature and submerge it with water and then heat it to 230F and each time we did that it constitutes one cycle (…) so the epoxy varnish is creating very good protection everywhere else except for this sharp corner and it's likely that because of this shape things crack … so that's what we're concentrating on …	00:126:15	S							
[…]	[…]=[TS presentation of corrosion solutions + can't understand audio]	00:132:48	-							
LR	So you've changed the overall process to systematically look at the pins now?	00:132:51	Q	[EXP]	Proc			In service	detection of failure by the supplier	D
TS	Hmm, no … since the pin failure we saw in August, we've gone into the pin redesign, design solutions … that is something we would do	00:133:30	S							
[LR]	[LR]=[can't understand him]	00:133:36	Q	[CLA]	Proc					
TS	We would hmm … based on the understanding of the problem … you were asking earlier what was driving that schedule, we would like to see a signing as soon as possible to minimise the number of units that are shifted with the old design … so that's why it's important for us to drive towards a design solution	00:134:07	S							
GW	Couldn't it be … if you had a bigger sample to look at you might revise that and say it changed to the pin material alone?	00:134:18	Q	[EXP]	Prod			Certification & testing	validity of testing by the supplier	D
TS	Well, you know … that's a legitimate question because the comments which we got back on this, hmm … the question was could we stick to the old design and make minor changes, specifically material change to possibly reduce the thrust loads? We looked at that and the bending stress loads are still high, I think they went up to 35000 psi and we'd really like them to be much lower than that …	00:135:01	S							
GW	Just really, I mean you don't know how valid that worst case is because again we're back to the situation shouldn't it cause failures in what is at least one order of magnitude if not two …	00:135:25	S	[CLA]	Proc					
TS	I understand, I think in this case, the … the bigger pin … the bigger pin hopefully won't contribute to any problems … especially as our analysis shows that stresses on the shaft are reasonable …	00:136:10	S							
GW	It's just that from a pedantic point of view you could argue that it would be very much quicker to get these items turned around and back into service with a very straight forward pin change	00:136:21	S							
TS	We need to replace … we still need a new thrust washer … the rework to the shaft isn't that complicated …	00:136:38	S							
[…]	[…]=[can't understand the audio: coughing noise, low voice]	00:137:15	-	-	-			-	-	-
GH	Yeah well, what wasn't clear is whether these pumps with 5000 hours had a process in place where they are being removed from the AC and returned to X	00:137:27	Q	[CLA]	Proc			Manufacturing & procurement	In service by the supplier	D
JL	I think we should have	00:137:29	A							
IB	To answer the question, I think we're having a look at it today	00:137:32	A							
[…]	[…]=[too much overlap]	00:138:20	-							
GH	I think maybe it would be better to wait for the Failure Mode and Effect Analysis that you've already been asked to include	00:138:27	S							
TS	That's right, that will be updated	00:138:32	S							
DW	I think that's a document for the CDR	00:138:35	S							
TS	Yeah (…)	00:138:55	F							
DW	Ok, thanks Graham	00:138:57	S							
[…]	[…]=[GH leaves, CS arrives]	00:142:32	-	-	-	Stator corrosion	C	-	-	-
TS	On the stator corrosion, there's a sample that's being passed around	00:142:37	S	[INF]	Prod			Systems design & Certification and testing	corrosion a design issue and a procurement issue	D
[TS]	[TS]=[presentation on stator corrosion]	00:152:47	S							
RF	Can I just say: it's getting more complex, because there are two separate issues … it's no longer just a process inclusion it's also a change of parts …	00:153:07	S	[DEB]	Proc					
JL	We could bring them up together in the modification …	00:153:12	S							
[…]	[…]=[background discussions between participants]	00:153:42	-							
LR	It approaches a reliability issue … I just worry, we so often combine things when one has to separate them, I think we just need to ask the question: JL, is it the same risk? …	00:154:10	Q	[EVA]	Ext					
DW	There are timescales aren't there? So it may not be feasible to put them together but we ought to combine them to make it easier all around …	00:154:27	S							
JL	(…) Are you going to lift your in service changing upon us …?	00:154:49	Q							
IB	That's a different issue to corrosion …	00:154:53	S							
[…]	[…]=[can't understand the audio]	00:157:30	-	-	-				-	
IB	Are you sure that the spray process, is the correct process?	00:157:35	Q	[DEB]	Proc			Production	spay method to apply varnish	P
TS	Hmm …	00:157:36	F							
IB	Because from my point of view it's easy to spray the OD of the rotor but not so easy to spray the ID of the stator and have a consistent finish	00:157:46	S							
TS	Yeah, I think the ultimate methods of applying varnish … we've had similar discussions with our suppliers and we feel that spraying is the best method …	00:158:32	S							
[…]	[…]=[can't understand the audio]	00:159:56	-	-	-				-	

Speaker ID	Intervention	Time	1	Exch role	Info type	Artefacts	Artefact type	Domain of competence	Topic	Topic Origin
LR	Pardon me, about the T-slot, why is that better?	00 160 01	Q	[DEB]	Prod			Systems design	Radius added to inside slot edges for stator configuration	P
TS	Well, the hmm … the idea there is that /	00 160 25	S							
LR	/It's just an edge breaker control//	00 160 27	Q							
TS	/Yeah it's just to give us a better control on the edges (…)	00 160 57	A							
TS	Personally I prefer the controlled edge break, I called the supplier (…) I like the idea of controlling the breaks	00 161 27	S							
LR	Not easy to control them …	00 161 29	S							
TS	Well, it … that's his concern (…) there are actually several methods that have been considered (…)	00 162 16	S							
TS	The stator that I have brought is to illustrate the problem … the hardware speaks for itself, it shows that problems always start on that edge …	00 162 38	S							
GW	(…) it's just because it is such a sharp edge that there is a lot of mechanical working by the (…)	00 163 14	S							
[…]	[…]=[everyone taking a look at the stator, audio difficult to understand]	00 164 34	-							
TS	I think the worst case is when it sits in place when you have a lot of condensation …	00 164 49	S							
[TS]	[TS]=[can't understand the audio]	00 166 10	S							
DW	In terms of the design improvements … are you looking to proceed with both of the designs anyway?	00 166 21	Q	[INF]	Proc			Systems design	supplier to carry out 2 variants of the design	P
TS	We are continuing with both anyway because until we've run tests to compare performance it doesn't make sense to us to propose a single solution	00 166 38	S							
DW	So in terms of … you're not looking for any feedback from AUK today?	00 166 46	Q	[CLA]	Proc					
TS	No /not necessarily/	00 166 50	A							
DW	/Just information/ to proceed ok	00 166 53	S							
[TS]	[TS]=[presentation]	00 169 41	S	[INF]	Prod & Proc	Concluding slide	Co			
RF	The DDP that we have from you, for the moment says that your reliability tests are not completed …	00 169 58	Q	[DEC]	Proc					
[…]	[…]=[silence]	00 170 40	-							
JL	It would be towards January for that type of testing	00 170 43	Q							
RF	With the 2 options …	00 170 47	Q							
TS	… yes …	00 171 11	A							
DW	(…) Can we go back to the PDR proper? Are we all clear on what needs to be done on the preparation for CDR documents?	00 171 27	Q	[MAN]	Proc			project management & business	preparation for CDR meeting and summary of actions	P
[JL]	[JL]=[goes through documents for CDR with DW TS and others … a lot of silences for reading … list of actions]	00 192 39	S							
DW	Are we all happy with the PDR being successful? … LR?	00 192 44	Q	[DEC]	Prod & Proc					
LR	… Well I suppose we ought to check what the chair of a PDR says? (laughs)	00 192 50	S							
DW	So I'm not going to go through all of it now but I think that the main points have come out, we've talked about our concerns with TS and he's going to hopefully address them … the agenda was … /what? … /	00 193 37	S							
LR	/(…)/ key milestones of course CDR and (…)	00 193 52	S							
[…]	[…]=[concluding remarks on forwarding documents and summary of actions by JL]	00 201 09	-							

APPENDIX D

RESULTS FROM THE TRANSCRIPT CODING OF THE AIRBUS UK PRELIMINARY DESIGN REVIEW

This appendix presents the tables of results based on the transcript coding of the Airbus UK Preliminary Design Review. These tables were used to build the graphs presented in chapter 5. The various tables have been grouped in 4 sections: intervention coding results, exchange roles coding results, information type coding results, and topic coding results.

1. TABLES OF RESULTS FOR THE INTERVENTION CODING

Overall intervention coding results		
Intervention types	**No.**	**%**
Statements	134	50%
Questions	68	25%
Answer	33	12%
Feeling	4	1%
Not Transcribed	28	10%

Speech time per role	
Roles	**% (time)**
Supplier Chief engineer	71%
DCS	3%
Chief Engineer's Office (Chairman)	4%
Safety	0%
Materials & Processes	3%
Engineering T/L-LR (Secretary)	17%
Systems Engineer	1%
Product T/L - LR	0%
Quality Procurement	0%

Speech time per meeting role	
Meeting roles	**% (time)**
Project team	71%
Review team	8%
Chair	4%
Secretary	17%

2. TABLES OF RESULTS FOR THE EXCHANGE ROLES CODING

Exchanges Roles - Overall results				
Exchange role category	**Time**	**% (time)**	**Number of exchanges**	**Time per exchange**
Exploring	00:07:18	4%	8	00:00:55
Clarifying	00:21:38	12%	21	00:01:02
Debating	00:18:35	11%	11	00:01:41
Evaluating	00:07:25	4%	3	00:02:28
Decision Making	00:13:10	8%	4	00:03:17
Managing	00:30:04	17%	4	00:07:31
Informing	01:08:18	39%	12	00:05:41
Resolving problems	00:03:17	2%	3	00:01:06
Digressing	00:04:40	3%	2	00:02:20

Evolution of exchange roles during the meeting (transcribed time)						
Time split	00:00:00 to 01:07:55		01:07:55 to 02:15:01		02:15:01 to 03:21:09	
Exchange role category	time	% (time)	time	% (time)	time	% (time)
Exploring	00:04:21	7%	00:02:57	6%	00:00:00	0%
Clarifying	00:10:18	15%	00:07:46	16%	00:03:34	6%
Debating	00:01:09	2%	00:09:15	19%	00:08:11	14%
Evaluating	00:01:56	3%	00:04:18	9%	00:01:11	2%
Decision Making	00:00:00	0%	00:03:10	6%	00:10:00	17%
Managing	00:08:36	13%	00:00:00	0%	00:21:28	37%
Informing	00:39:36	59%	00:15:11	31%	00:13:31	23%
Resolving problems	00:00:53	1%	00:02:24	5%	00:00:00	0%
Digressing	00:00:03	0%	00:04:37	9%	00:00:00	0%

Intervention type and Exchange roles								
Exchange role category	No. Statements	% S	No. Questions	%Q	No. Answers	%A	No. Feelings	%F
Exploring	7	29%	11	46%	6	25%	0	0%
Clarifying	27	44%	21	34%	12	19%	2	3%
Debating	33	61%	15	28%	5	9%	1	2%
Evaluating	10	59%	5	29%	2	12%	0	0%
Decision Making	13	68%	4	21%	1	5%	1	5%
Managing	16	67%	6	25%	2	8%	0	0%
Informing	22	81%	3	11%	2	7%	0	0%
Resolving problems	5	45%	3	27%	3	27%	0	0%
Digressing	-	-	-	-	-	-	-	-

3. TABLES OF RESULTS FOR THE INFORMATION TYPE CODING

Overall information type timing			
Information type	No. Exchanges	Time	% (time)
Process Information	35	01:16:51	42%
Product Information	28	01:32:51	51%
Resources Information	0	00:00:00	0%
External Factors Information	6	00:12:44	7%

Evolution of information type during the meeting									
Time split	00:00:00 to 01:07:55			01:07:55 to 02:15:01			02:15:01 to 03:21:09		
Information type	No. Exch.	Time	% (time)	No. Exch.	Time	% (time)	No. Exch.	Time	% (time)
Process Information	14	00:23:17	35%	11	00:13:19	29%	10	00:40:15	58%
Product Information	9	00:43:32	65%	15	00:21:32	46%	4	00:27:47	40%
Resources Information	0	00:00:00	0%	0	00:00:00	0%	0	00:00:00	0%
External Factors Information	0	00:00:00	0%	5	00:11:33	25%	1	00:01:11	2%

Exchange roles and information types (% time)			
	Information types		
Exchange roles	Process information	Product information	External Factors information
Exploring	79%	21%	0%
Clarifying	66%	18%	16%
Debating	36%	43%	20%
Evaluating	0%	26%	74%
Decision making	58%	42%	0%
Managing	100%	0%	0%
Informing	6%	94%	0%
Resolving problems	49%	51%	0%

4. TABLES OF RESULTS FOR THE TOPIC CODING

Domain of competence timing		
Domains of competence	**Time**	**% (time)**
Project management and business	00:46:00	23%
Certification and testing	00:53:50	27%
Systems design	01:34:35	47%
Manufacturing and procurement	00:03:44	2%
In-service	00:02:04	1%

Topic Origin	
Origin of the topic discussed	**% (time)**
Predetermined	65%
Derived	35%
Unexpected	0%

APPENDIX E

MEETING CAPTURE TEMPLATES AND RESULTS FROM THE CAMAQ PROJECT CASE STUDY

This appendix presents the tables of results based on the Meeting Capture Templates (MCT) collected from the CAMAQ case study. 2 examples of MCT are presented to illustrate the evolution of the template; a sheet from the first and second version of the MCT completed by a student from the CAMAQ project team have been scanned and included in this appendix.

1. FIRST VERSION OF THE MEETING CAPTURE TEMPLATE

#	Topic (in a few words)	Who?	What?		Impact on design and manufacture?	Time
6	Shear stress of skin. Ex: wing of a/c takes a lot of shear loads on skin.	[ ] Students [x] Customers [ ] Consultants	[ ] Exploring [x] Evaluating [ ] Debating	[ ] Clarifying [ ] Decision [ ] Informing	[ ] Process [x] Product [ ] Tools	9:20
7	Concept # 1 weight?	[ ] Students [ ] Customers [x] Consultants	[ ] Exploring [x] Evaluating [ ] Debating	[ ] Clarifying [ ] Decision [ ] Informing	[ ] Process [x] Product [ ] Tools	9:21
8	Which concept closest to thrust line?	[ ] Students [ ] Customers [x] Consultants	[ ] Exploring [ ] Evaluating [ ] Debating	[x] Clarifying [ ] Decision [x] Informing	[ ] Process [x] Product [ ] Tools	9:23
9	Longitudinal dimensions? Length of engine is to be considered.	[ ] Students [x] Customers [ ] Consultants	[ ] Exploring [x] Evaluating [ ] Debating	[x] Clarifying [ ] Decision [ ] Informing	[ ] Process [x] Product [ ] Tools	9:24
10	Solutions require major changes to structure: are you to ask formally for it to customers?	[ ] Students [ ] Customers [x] Consultants	[ ] Exploring [x] Evaluating [ ] Debating	[ ] Clarifying [ ] Decision [ ] Informing	[ ] Process [x] Product [ ] Tools	

#	Topic (in a few words) and Action (+ name)	Who?	What?	Impact on design and manufacture?	Time
5	Two options? or a permenent change on all production? Action: tow options	☐ Struct ☐ Sys ☐ Certif ☐ Magt ☑ BA ☐ PWC ☐ Bell ☑ Cons	☐ Exploring ☑ Clarifying ☐ ~~Students~~ Evaluating ☐ Decision ☐ Debating ☐ Informing	☑ Process ☐ Product ☐ Tools	9:22
6	Does the member take any thrust? Action: No	☐ Struct ☐ Sys ☐ Certif ☐ Magt ☐ BA ☑ PWC ☐ Bell ☐ Cons	☐ Exploring ☑ Clarifying ☐ ~~Students~~ Eval ☐ Decision ☐ Debating ☐ Informing	☐ Process ☑ Product ☐ Tools	9:25
7	Why is flange at back of mount so square? Action:	☐ Struct ☐ Sys ☐ Certif ☐ Magt ☑ BA ☐ PWC ☐ Bell ☐ Cons	☐ Exploring ☐ Clarifying ☐ ~~Students~~ Eval ☐ Decision ☐ Debating ☑ Informing	☐ Process ☑ Product ☐ Tools	9:27
8	Have you check by analysis for beam fasteners? Action: Will need to be done in COR	☐ Struct ☐ Sys ☐ Certif ☐ Magt ☐ BA ☐ PWC ☐ Bell ☑ Cons	☐ Exploring ☐ Clarifying ☑ ~~Students~~ Eval ☐ Decision ☐ Debating ☐ Informing	☐ Process ☑ Product ☐ Tools	9:29

3. CAMAQ PROJECT CASE STUDY: TABLES OF RESULTS BASED ON THE COLLECTED MEETING CAPTURE TEMPLATES

Overall participant role timing					
Participant roles		Requirement Review	Concept Review	Preliminary Design Review	Critical design Review
Project Management	Time	00:37:00	00:30:30	00:11:00	00:17:00
	% (meeting time)	28%	20%	5%	6%
Structure	Time	00:19:00	00:27:00	00:34:00	00:51:00
	% (meeting time)	14%	18%	17%	19%
Systems	Time	00:13:00	00:04:00	00:22:00	00:41:00
	% (meeting time)	10%	3%	11%	16%
Airworthiness	Time	00:11:00	00:19:00	00:25:00	00:00:00
	% (meeting time)	8%	13%	12%	0%
Manufacturing	Time	00:07:00	00:06:00	00:23:00	00:52:00
	% (meeting time)	5%	4%	11%	20%
Total for project team	% (meeting time)	65%	58%	57%	61%
Client (review team)	Time	00:47:00	01:02:30	01:26:00	01:41:00
	% (meeting time)	35%	42%	43%	39%

Overall exchange roles timing					
Exchange roles		Requirement Review	Concept Review	Preliminary Design Review	Critical Design Review
Informing	Time	00:43:00	00:58:30	01:07:00	01:45:00
	% (meeting time)	47%	45%	41%	52%
Clarifying	Time	00:22:00	00:21:30	00:39:00	00:55:00
	% (meeting time)	24%	17%	24%	27%
Debating	Time	00:02:00	00:18:00	00:05:00	00:09:00
	% (meeting time)	2%	14%	3%	4%
Exploring	Time	00:07:00	00:08:30	00:17:00	00:19:00
	% (meeting time)	8%	7%	10%	9%
Evaluating	Time	00:11:00	00:19:00	00:27:00	00:15:00
	% (meeting time)	12%	15%	17%	7%
Decision making	Time	00:06:00	00:04:30	00:07:00	00:00:00
	% (meeting time)	7%	3%	4%	0%

Overall general topic timing					
Topics (general)		Requirements Review	Concept Review	Preliminary Design Review	Critical Design Review
Design	Time	00:44:00	01:20:00	01:55:00	02:17:00
	% (meeting time)	45%	58%	67%	65%
Manufacture	Time	00:10:00	00:03:00	00:37:00	00:48:00
	% (meeting time)	10%	2%	22%	23%
Management	Time	00:43:00	00:54:00	00:20:00	00:26:00
	% (meeting time)	44%	39%	12%	12%

Overall product vs. process information timing					
Information types		Requirement Review	Concept Review	Preliminary Design Review	Critical Design Review
Product information	Time	00:45:00	01:05:00	01:30:00	01:51:00
	% (meeting time)	44%	45%	49%	56%
Process information	Time	00:57:00	01:18:00	01:32:00	01:29:00
	% (meeting time)	56%	55%	51%	44%

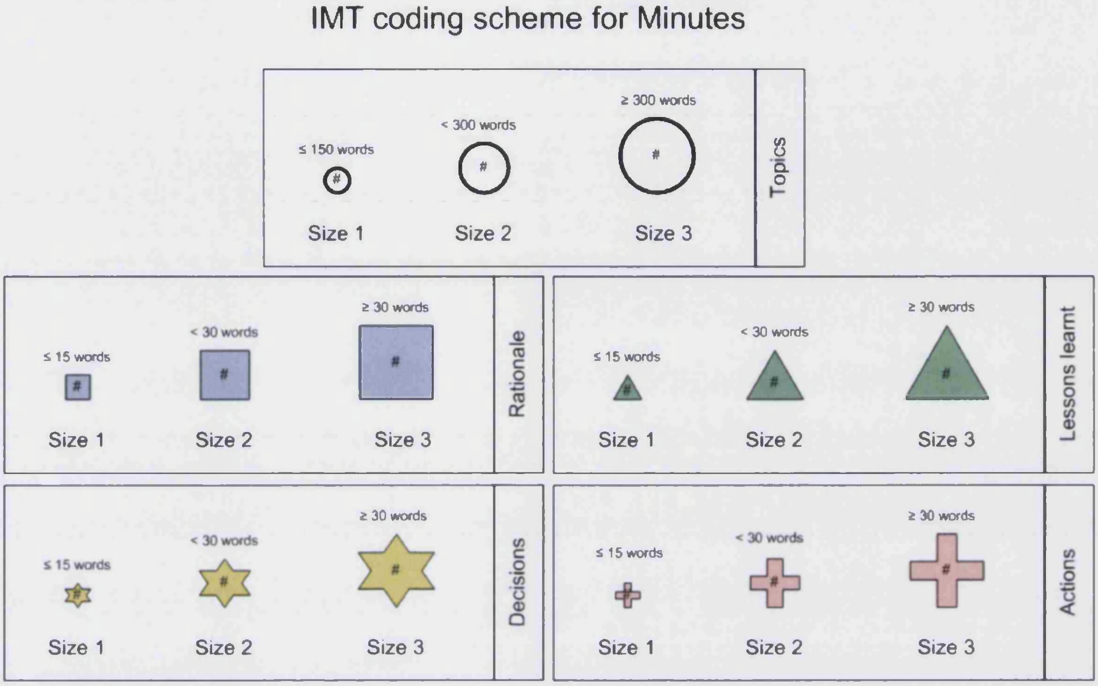
APPENDIX F

DETAILED INFORMATION MAPPING RESULTS OF THE AIRBUS UK REQUIEREMENT REVIEW

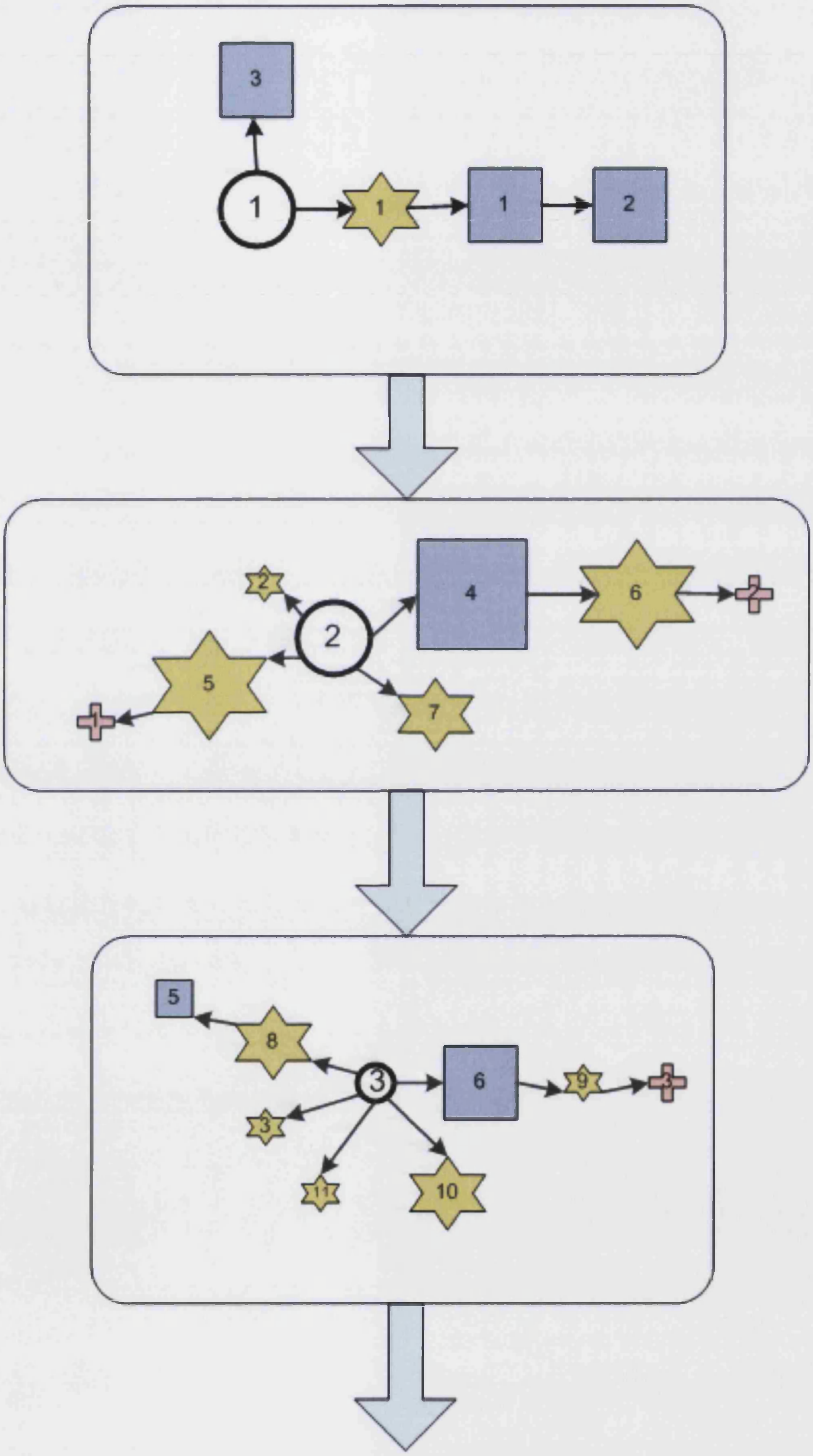
This appendix presents the detailed information mapping results generated by the Information Mapping Technique (IMT) used for the knowledge loss study of the Airbus UK Requirement Review.

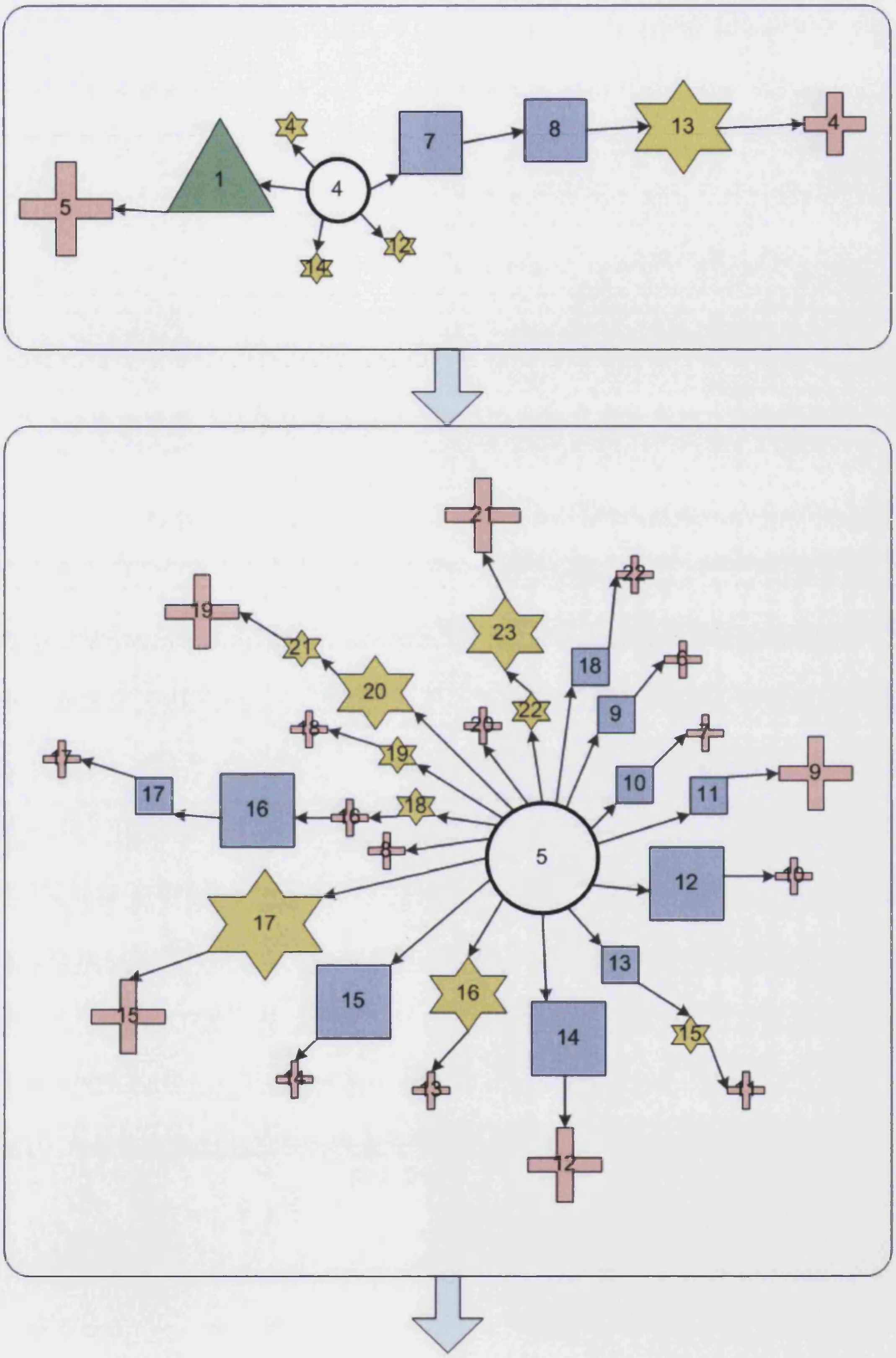
1. DETAILED INFORMATION MAPPING RESULTS FOR THE MINUTES OF THE AIRBUS UK REQUIREMENT REVIEW

1.1. The coding scheme used by the Information Mapping Technique for the minutes



1.2. The complete information maps for the minutes of the Airbus UK Requirement Review

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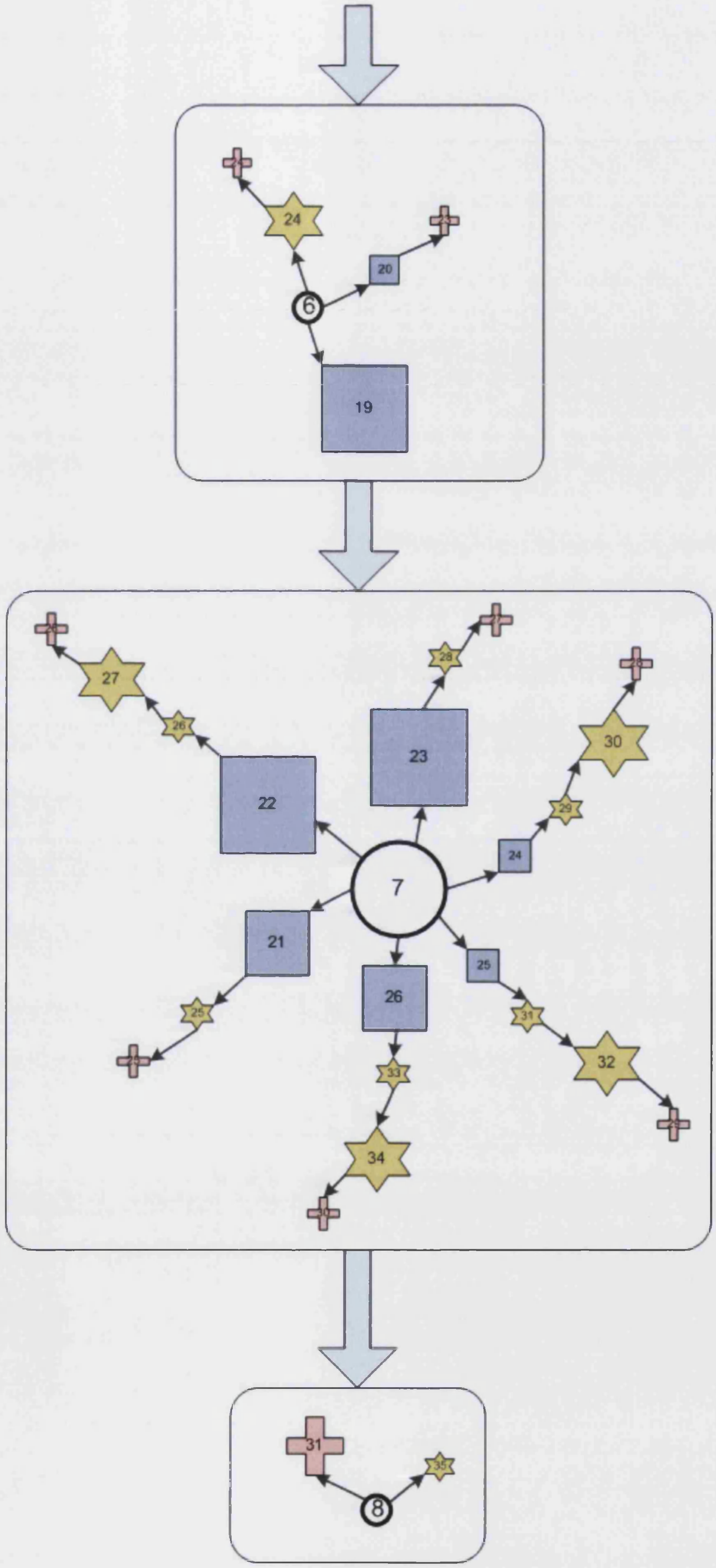
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1.3. Register tables for each type of knowledge element displayed in the information maps of the minutes

Topics in the Airbus UK RR minutes			
#	Summary	No. of words	Coding size
1	Introduction and objectives	189	2
2	Dry bay deletion	182	2
3	Fuel leak detection	142	1
4	General changes on computer software requirements	233	2
5	Management plan	657	3
6	Certification plan	141	1
7	Risk register	300	3
8	Agreement to proceed, review of actions	102	1

RR minutes - Rationale elements			
#	Summary	No. of words	Coding size
1	Homogenize the Single Aisle Fleet for Fuel Leak Detection and Dry Bay Deletion functions	16	2
2	Update stage 7.0 software to 8.0	27	2
3	Ensure all requirements are identified and are correct and captured	28	2
4	*Supplier* model converts 2 dry bays per wing to one dry bay	57	3
5	The more accurate method and the easier for the supplier to implement	15	1
6	'Minimise' is too subjective	16	2
7	Concern was raised regarding demonstration of maturity based upon the lessons learned from the A320 FQIC	17	2
8	Ensure that Goodrich deliver a suitable verification plan.	24	2
9	The mod number in section 2.4.1 introduces the H2-F2 standard FWC	12	1
10	The mod number introducing the V50 standard DMC has too many digits	12	1
11	Sections 3, 4 & 5: the 'Inputs to task' and 'outputs from task' document lists are confusing	12	1
12	Section 3: the DDP is not mentioned as either an input or output document	16	2
13	The objectives of the Validation Plan are incomplete	4	1
14	4.2: the validations to be performed by the supplier are not comprehensive enough	16	2
15	4.3.1: a V & V plan should be an input from the supplier	16	2
16	If the number of reviews increases then section 4.4 will need to be amended accordingly	20	2
17	Information regarding any additional reviews can be found in AP2288	15	1
18	The verification activities are not described in enough detail to act as a useful plan	15	1
19	The certification plan was produced in Phase 1 but will be reviewed during the critical design review	32	3
20	Is ARP 4754 applicable to this development?	7	1
21	Rig testing has yet to begin and damage could occur at any time	21	2
22	If this RMI is incorrect then this would cause an even larger delay for re-work	35	3
23	There will not be a change to the FWC or DMC	30	3
24	An ACT fitted aircraft may not be available for flight-testing	10	1
25	The top-level dry bay deletion requirements may change as the dry bay deletion task evolves	15	1
26	A320 Lessons learned document may not be available in time to influence the A321 development	18	2

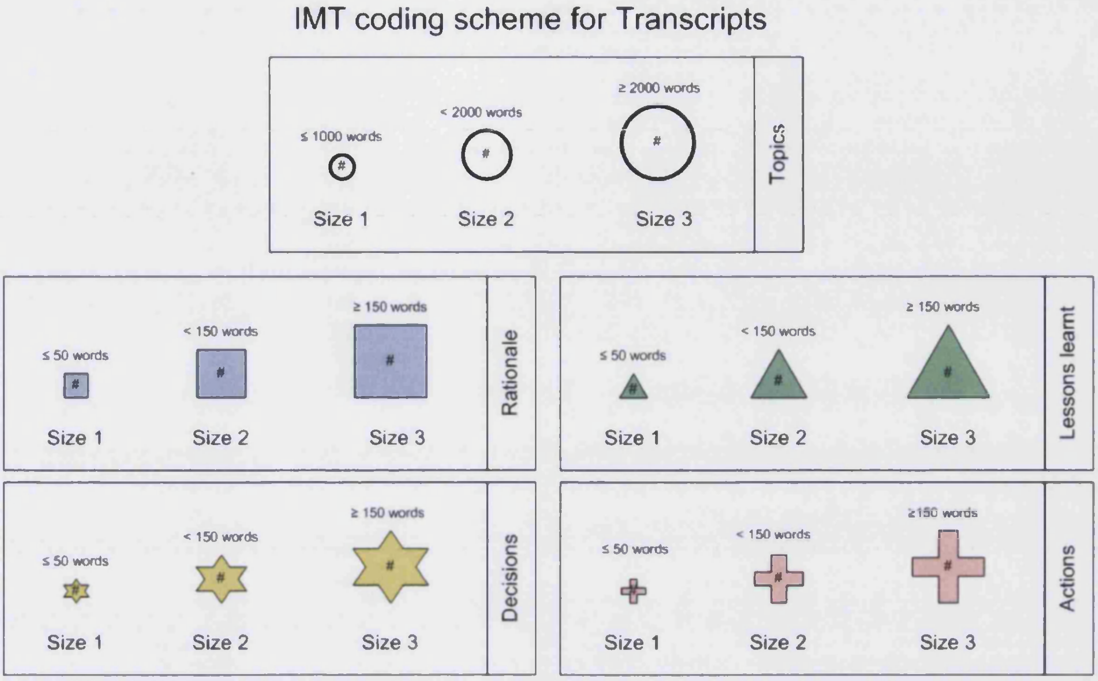
RR minutes - Lessons learnt elements			
#	Summary	No. of words	Coding size
1	Based on the A320 FQIC, *Supplier* should continue to manufacture and support the existing software standard	43	3

RR minutes - Decisions elements			
#	Summary	No. of words	Coding size
1	The A321 FQIC to include a Fuel Leak Detection function and provision for Dry Bay deletion	28	2
2	addition of Dry Bay Deletion Requirements to section 2.2.1	10	1
3	addition of Fuel Leak Detection Requirements	7	1
4	General changes to remove TBDs etc.	7	1
5	There should be an approximate value for the additional fuel quantity after removal of dry bays	32	3
6	The requirement results in two possible wing configurations: dry bays installed or not installed	36	3
7	The other requirements in section 2.2.1 were acceptable	19	2
8	The method for the threshold calculation was as the A319CJ	25	2
9	Spurious Fuel Leak Alerts should be quantified	8	1
10	minor alterations for clarity will be captured in the issued copy of the Equipment Specifictaion	28	2
11	The remainder of the Fuel Leak Detection requirements were acceptable	10	1
12	ABD0015 should be changed to ABD0100 for a D0178B development	10	1
13	More robust fault finding activities could be investigated to reduce the number of No Fault Found returns from in-service issues	32	3
14	Aircraft level requirements had been captured in the Equipment Specification	15	1
15	Include the following statement 'Ensure that the Aircraft level requirements are included, complete and correct'	15	1
16	Section 4.1: incorrect reference	18	2
17	Split the 'First Flight Review meeting' into a Test Readiness review and a Flight test Readiness review	46	3
18	section 6.1: incorrect reference	4	1
19	Add the word 'Certification' in the second sentence before the word 'Requirements'	12	1
20	The supplier should also perform integration testing, system testing etc	23	2
21	The testing will be detailed in the supplier validation and verification plan	10	1
22	Include V & V plan from the supplier in section 5.4.	11	1
23	The chief engineers office requests that any development and certification FTRs are progressed as soon as possible	22	2
24	The word 'proved', section 3 paragraph 2, is inappropriate and should be changed	22	2
25	Risk ID 10, status set to open	1	1
26	Risk ID 15, status set to open	1	1
27	Provide the RMI once the required changes are fully understood.	16	2
28	Risk ID 16, status set to closed	1	1
29	Risk ID 20, status set to open	1	1
30	The risk was identified during the meeting and will be added to the current Risk Register.	16	2
31	Risk ID 21, status set to open	1	1
32	The risk was identified during the meeting and will be added to the current Risk Register.	16	2
33	Risk ID 22, status set to open	1	1
34	The risk was identified during the meeting and will be added to the current Risk Register.	16	2
35	agreement was reached to proceed to the next phase of the development	12	1

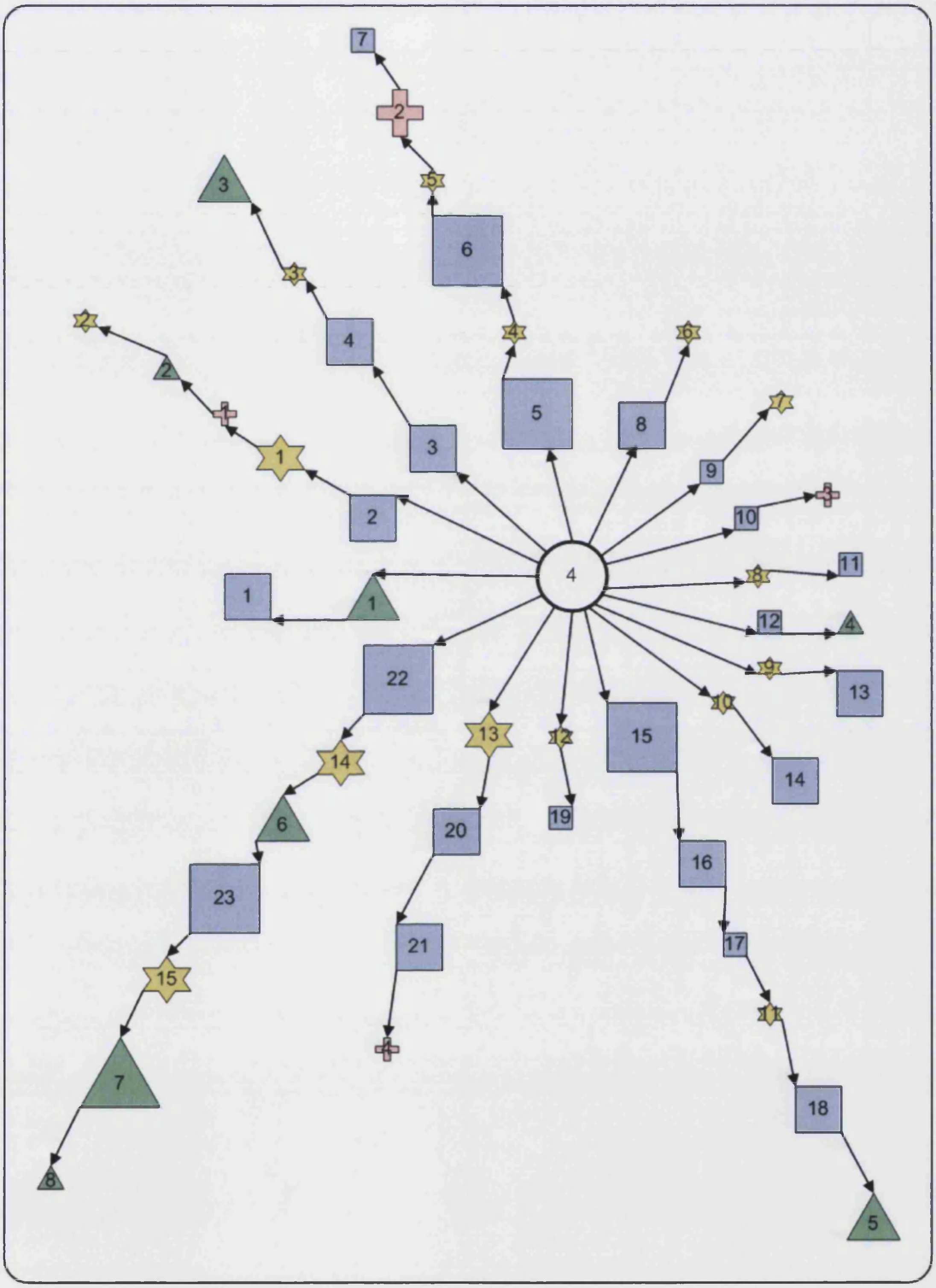
RR minutes - Action elements			
#	Summary	No. of words	Coding size
1	Include an approximate dry bay quantity in the Equipment Specification	15	1
2	Clarify and confirm the top-level requirement for dry bay deletion	15	1
3	Determine the probability of spurious alerts	9	1
4	Ensure that Goodrich is aware of the need for a robust verification plan including maturity demonstration	21	2
5	Ensure commercial agreement prevents *Supplier* from stopping production of stage 7.0 until maturity of stage 8.0	33	3
6	Find out and include the relevant mod number	8	1
7	Find out and correct the mod number introducing the V50 DMC	11	1
8	Investigate if the SDAC is required for the Fuel Leak Detection Function	12	1
9	Review the 'Inputs to task' and 'outputs from task' document lists and add clear definition of usage for each	19	2
10	Include DDP and associated documentation in the revised sections of the management plan	13	1
11	Update the management plan in-line with comments	7	1
12	Investigate and include in the plan, information regarding the validation exercises to be performed by the supplier	17	2
13	Correct the reference	3	1
14	Update the Plan	3	1
15	Consider and if accepted update the Management Plan and the Programme plan to accommodate suggested reviews	17	2
16	Correct management plan with correct reference	6	1
17	Update the Plan in accordance with the result of action 15	11	1
18	Update the plan	3	1
19	Further define the levels of testing expected of the supplier and ensure that theV&V plan meets these requirements	22	2
20	Plan some maturity testing to take place at the *supplier*	10	1
21	Amend section 5.4 to include the supplier V&V plan. Note: The FTRs are due for production in January 2004	19	2
22	Further populate the verification activities to a higher level of detail	11	1
23	Investigate ARP475 applicability and if necessary alter the plan	9	1
24	Update the plan	3	1
25	Change Risk ID 10: set status to open	1	1
26	Change Risk ID 15: set status to open	1	1
27	Change Risk ID 16: set status to closed	1	1
28	Change Risk ID 20: set status to open	1	1
29	Change Risk ID 21: set status to open	1	1
30	Change Risk ID 22: set status to open	1	1
31	Check that PS is happy to proceed to the next phase of development	16	2

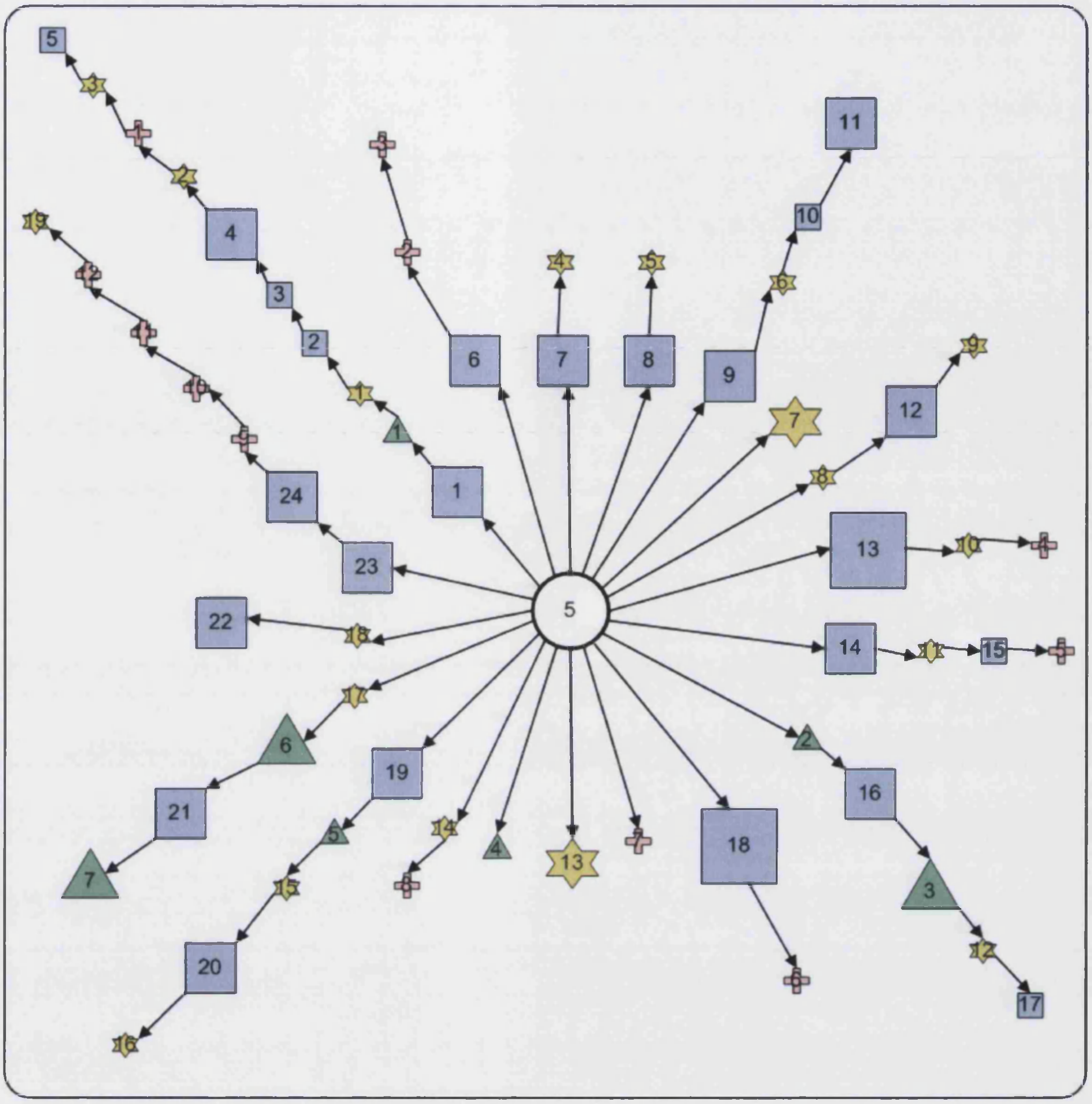
2. DETAILED INFORMATION MAPPING RESULTS FOR THE TRANSCRIPT OF THE AIRBUS UK REQUIREMENT REVIEW

2.1. The coding scheme used by the Information Mapping Technique for the transcript



2.2. The information maps for topics 4 and 5 in the transcript of the Airbus UK Requirement Review





2.3. Register tables for each type of knowledge element displayed in the information maps of topics 4 and 5 in the transcript

Topics in the Airbus UK RR transcript			
#	Summary	No. of words	Coding Size
1	Meeting management (including review of actions)	1849	2
2	Dry Bays	939	2
3	Fuel leak detection based on A320	395	1
4	New equipment specifications for the supplier	6488	3
5	Project management and Management Plan issues	4353	3
6	Certification plan	953	2
7	Risk register	1607	2
8	Agreement to proceed	524	1

2.3.1. Register tables for topic 4 in the transcript

Topic # 4 - RR transcript - Rationale elements			
#	Summary	No. of words	Coding size
1	review the V&V plan for suppliers for their software, hardware and integration to avoid recent failures	80	2
2	Software was previously developped to standard DO 178 A, has moved on to version B, the modification should be made according to B but the entire software does not need to be validated to B	139	2
3	Implications of moving to the DO178 B standard	105	2
4	DO178B makes sure AUK get a decent product	91	2
5	in case of hardware change the integration with the new software must be ensured	174	3
6	for commercial agreement purposes, the verification activities required by the supplier need to be explicit in the specs otherwise AUK will pay extra for these activities	182	3
7	verification details must not be in management plan as it is an internal document	8	1
8	Problem reports have been reviewed but are not included in these documents, a side meeting with the supplier is the preferred option	103	2
9	certification plan requires JAR25 change 11 and issue 7 ensures we comply with change 11	30	1
10	Direct Maintenance costs targets for new equipment at TBD	9	1
11	a CREE is in preparation to do with the applicability of the new software	38	1
12	procurement has placed a requirement for bar codes	22	1
13	difference between two way and one way interchangeable fuel leak detection function	74	2
14	the requirement on supplier only through procurement channel as leaves current standard validation too late	84	2
15	the 'minimise' term mut be quantified for spurious warnings or cautions a form of risk assesment must be made	370	3
16	figures must be searched for spurious warning limits	114	2
17	difficult to give targets hence the loose terminology	49	1
18	the spurious warning is more a caution than a safety feature	91	2
19	all design specs need to be validated by PFS	41	1
20	the specs have been compared to A320 and 2 ACTs but the maths were not done	65	2
21	a degree of validation must be shown by the supplier i.e. the algorithm work properly	79	2
22	new EN spec will be applicable to hardware changes	150	3
23	the requirements are consistent with other A/C particularly single aisle fleet where commonality is sought, commonality is being maximised	212	3

Topic # 4 - RR transcript - Lessons Learnt elements			
#	Summary	No. of words	Coding size
1	problems with suppliers seem to be linked to the V&V standards imposed	71	2
2	other suppliers have been witnessed to use DO178B	41	1
3	certification and qualification specs have not been sufficiently detailed in the past	122	2
4	From what was seen on other suppliers, bar codes are required through ABD 0100	20	1
5	During flight it wold be a sick joke to have a warning too late	134	2
6	problems in suppliers ATPs need to be tracked and checked for weaknesses	83	2
7	they will typically test returned units with their software and declare no faults based on these ATP, when the problem comes from the software compatibility	204	3
8	we have previously released software with known problems which would fail ATPs	13	1

Topic # 4 - RR transcript - Decisions elements			
#	Summary	No. of words	Coding size
1	modifications are made to B, integration to B, but software remains validated against A	65	2
2	DO178B taken into account by suppliers	11	1
3	reflect move to DO178B in the specs	11	1
4	insert statement to cover integration in case of any hardware changes linked to new software	8	1
5	insert detailed verification activities in the specs	7	1
6	problems will be covered by a commercial agreement and fixed during a side meeting	34	1
7	issue 7 and JAR25 change 11 are the same	12	1
8	final note may be superseeded by a final issue of certification review items	14	1
9	retrofitability: the new equipement is one way interchangeable on condition with no impact on the specs	18	1
10	the change in manufacture from old to new will be agreed by airbus and stated in commercial agreement for the program	46	1
11	threshold set and the gauging for the spurious warning can be submitted to chief engineers for validation	37	1
12	review of the step function by PFS	13	1
13	design requirement 9e) must be worded as 2 or more tanks	72	2
14	for intrinsic safety ... unless hardware change use old standard	69	2
15	on ATP only comments can be made, and these only check the hardware	87	2

Topic # 4 - RR transcript - Action elements			
#	Summary	No. of words	Coding size
1	update equipement spec to match DO178B subject to discussion with supplier	33	1
2	insert verification details in the specs document that will be passed on to the supplier	70	2
3	Check for DMC that should be identifified in specs	48	1
4	check supplier's model tomorrow when they visit Airbus	34	1

2.3.2. Register tables for topic 5 in the transcript

Topic # 5 - RR transcript - Rationale elements			
#	Summary	No. of words	Coding size
1	Applicability of the General Requirements for Equipment and System Suppliers (AP 1013) to this project	112	2
2	The GRESS is referred to in the ABD 200 which is not applicable to this project	49	1
3	GRESS has been approved by SupplierX as a general compliance document	25	1
4	It's a large document and there might be a lot of information overload for just a modification	76	2
5	it is not a requirement from chief engineer's office to apply GRESS	16	1
6	The management plan should mention the pin programming	59	2
7	The issue number of the referenced documents	108	2
8	All documents can be considered as an output or input to something	126	2
9	The DDP should be mentionned somwhere	63	2
10	The document set from the vendor was not mentionned for software insurance reasons	23	1
11	the list of document presented should be better defined	61	2
12	The responsibilities of the partners involved and AUK should be expanded to show what sort of validations are required	78	2
13	The validation requirements need to be detailed to show the way, the level, the quantity etc. hat the supplier needs to meet	207	3
14	Validation and Verification plan from Supplier	74	2
15	The software certification plan might be included in their V&V	28	1
16	flight test review	59	2
17	Flight limitation certificates to be resolved	18	1
18	reviews that contribute to verification	176	3
19	software/hardware compatibility needs to be guaranteed regardless of system/subsystem/equipment guidelines	127	2
20	commonalities between the A320 and A321	58	2
21	the type of A/C for the flight tests needs to be specified	55	2
22	detail of the possible rig testing requirements	123	2
23	Maturity testing from the supplier needs to be defined	61	2
24	Intention of the summary table page 11	70	2

Topic # 5 - RR transcript - Lessons Learnt elements			
#	Summary	No. of words	Coding size
1	The GRESS is mentionned more and more regularly in engineering documents	14	1
2	remember to follow up actions	25	1
3	In the past it has never been determined if a system was safe for first flight	85	2
4	Improve the flow of AP s and AM s down to projects	30	1
5	on the 319 CJ spec the FQIC was called an equipment to avoid this problem	40	1
6	problems in the past linked to confusion between certification flight tests and development flight tests	70	2
7	testing which requires an A/C needs to be planned well in advanced	62	2

Topic # 5 - RR transcript - Decisions elements			
#	Summary	No. of words	Coding size
1	The GRESS was not planned to be referenced in this project	18	1
2	Both engineering and commercial must review the applicabiility of GRESS for this project	45	1
3	If Supplier are using it, GRESS should be reviewed to sort out what is applicable	15	1
4	The referenced documents shouldn't include their issue number unless it's not the latest issue which is being used	9	1
5	The breakdown of the document list should be revised (they should all fit into input and output)	15	1
6	The DDP should be in the approval dossier	7	1
7	The validation plan objectives are correct	95	2
8	Wording for the responsibilities for validation are incomplete	9	1
9	The management plan should detail wha sort of validation the supplier is requested to do	24	1
10	Validation requirements should be stated in part a of the spec and reminded at the end of the spec	19	1
11	the supplier needs to send both the V&V document and the software certification plan	6	1
12	Test readiness review before testing equipment and flight readiness test before flight	18	1
13	Detail the goal of each review and their respective validation requirements based on AP 2288 or the single aisle document policy	125	2
14	only certification requirements come from airworthiness	40	1
15	*Supplier* is responsible for the software and the hardware but the verification requirements need to be well defined	38	1
16	No verification testing is required for compatibility between FWC and DMC	42	1
17	decision on whether it's a development flight test or certification flight test	31	1
18	More detail is needed for the verification activities	25	1
19	the secretary will be opened to any further comments after the meeting	12	1

Topic # 5 - RR transcript - Action items			
#	Summary	No. of words	Coding size
1	Check with Supplier how AP 103 is used on this project	24	1
2	Check mod number for the DMC, there seems to be an extra '1'	45	1
3	Check the flight warning number	18	1
4	correct typo, validation activities are detailed in the spec section 4.4 not 5.4	20	1
5	Request for the supplier's V&V plan	9	1
6	Supplier results should be seen as an output	18	1
7	typo referring to section 6.1	10	1
8	the verification requirements do not only come from airworthiness, this should be made clear in the text	16	1
9	page 11 change 'any can" to 'any can't'	30	1
10	page 11 change 'dry bay detection' to 'dry bay deletion'	17	1
11	number on the front sheet is 1559 and the other sheets are 1599	16	1
12	typo: page 6, change 'complied' to 'compiled'	18	1

APPENDIX G

THE QUESTIONNAIRE USED FOR THE "MEETING MINUTES SURVEY"

This appendix presents the questionnaire that was distributed to aerospace companies in Canada and Europe in 2005.

Survey on the role of minutes in the aerospace industry design process

As part of a research project taking place at the University of Bath (United Kingdom) and the École Polytechnique de Montréal (Canada), a study of minutes* in the aerospace industry is being undertaken.

This study aims to establish how engineers use minutes* in their activities and how their companies integrate them in their business/design process. In order obtain data relating to current practices we would like to ask for your assistance in completing a short questionnaire. The purpose of this questionnaire is to find out if engineers actively refer to minutes* of past design reviews and establish what type of information contained in these documents is particularly useful to their work.

This questionnaire has been designed in Microsoft Word as a form. You may select the appropriate option by clicking on the check box with your mouse, or typing in the spaces provided. **The questionnaire should take around five minutes to complete.**

<u>All information will be treated as strictly confidential. The results will be presented as general trends so that no individuals or organisations can be identified.</u>

Completed questionnaires can either be sent electronically to g.huet@bath.ac.uk or posted to:

Steve Culley
Department of Mechanical Engineering
University of Bath
Bath
BA2 7AY
United Kingdom

Clément Fortin
Département de Génie Mécanique
École Polytechnique de Montréal
C.P. 6079, succ. Centre-ville
Montréal (Qc)
Canada H3C 3A7

If you have any questions, or would like to comment on anything in more detail, please contact me directly.

Many thanks for your co-operation with this study.

Gregory Huet
Tel: +1 514 340 4711 # 3436

* Minutes refer to the official record of the proceedings of a meeting.

Please select one box only per question, unless instructed otherwise.

Name (optional): **Company (optional):** **Age:**

Q1. In which country did you study engineering?

Country:

Q2. Were you taught to take minutes during your engineering studies?

- ☐ Yes
- ☐ No

Q3. Which engineering domain best describes the team you work with?

- ☐ Project Management
- ☐ Advanced/Concept Design
- ☐ Manufacturing
- ☐ Quality management
- ☐ Structural analysis
- ☐ Aerodynamics
- ☐ Systems integration
- ☐ Airworthiness
- ☐ Procurement
- ☐ Knowledge / information management
- ☐ Other (please specify)

Q4. Is it part of your company policy to take minutes during engineering meetings?

- ☐ Yes, for all meetings
- ☐ Yes, for formal meetings
- ☐ Yes, for some meetings
- ☐ No policy on minute taking

Q5. Does your company provide engineers with a formal minutes template?

- ☐ Yes, there are various formal templates according to the type of meeting
- ☐ Yes, there is a single formal template acknowledged by the company
- ☐ No but there is an informal template used by engineers
- ☐ No

Q6. Where are design review minutes archived? **(Select all that apply)**

- ☐ On the author's computer
- ☐ In a document repository / vault linked to the project
- ☐ In a knowledge/information data store
- ☐ In a management/business data store
- ☐ In a data store used for legal purposes
- ☐ In a product structure tree
- ☐ They are linked to the project road map
- ☐ Other (please specify)

Q7. When other companies are involved, are the minutes of the design reviews shared?

- ☐ Yes
- ☐ Sometimes
- ☐ No

Q8. How long does it usually take to issue the minutes of a design review? **(Select all that apply)**

- ☐ In line with company policy
- ☐ They are ready at the end of the meeting
- ☐ A few hours after the meeting
- ☐ The next day
- ☐ Within a week
- ☐ Up to a month
- ☐ More than a month

Q9. What sections typically constitute the minutes of design reviews? **(Select all that apply)**

- ☐ List of attendees
- ☐ Agenda
- ☐ Introduction
- ☐ Objectives / Aims
- ☐ Summary of topics discussed
- ☐ Distribution
- ☐ List of decisions
- ☐ Lessons learnt
- ☐ List of actions
- ☐ Agreement to proceed
- ☐ Authorization
- ☐ Other (please specify)

Q10. From the same list, pick the sections which you refer to most for the purpose of your work? **(Select a maximum of 3)**

- ☐ List of attendees
- ☐ Agenda
- ☐ Introduction
- ☐ Objectives / Aims
- ☐ Summary of topics discussed
- ☐ Distribution
- ☐ List of decisions
- ☐ Lessons learnt
- ☐ List of actions
- ☐ Agreement to proceed
- ☐ Authorization
- ☐ Other (please specify)

Q11. For what purpose do you think minutes are kept? **(Select all that apply)**

- ☐ For legal purposes
- ☐ To follow company policy
- ☐ As a formal reminder of actions to take
- ☐ As a written proof of the project's progress
- ☐ As an input/output of the design process
- ☐ Other (please specify)

Q12. Please qualify the following statements

	True	**Mostly true**	**Sometimes**	**False**	**Don't know**
a) Minutes have an active role in the design process of any project	☐	☐	☐	☐	☐
b) Minutes are useful for revisiting the design process at a given stage	☐	☐	☐	☐	☐
c) Minutes are procedural documents with a limited impact on the engineer's work	☐	☐	☐	☐	☐
d) It is important that the minutes are taken by an engineer working on the project	☐	☐	☐	☐	☐
e) Minutes are essential for the management of a project	☐	☐	☐	☐	☐
f) Minutes record design rationale and lessons learnt	☐	☐	☐	☐	☐

Q13. Do you have any further comments on the role of minutes in the aerospace design process?

Thank you. Please save and email completed questionnaires to g.huet@bath.ac.uk or post to Steve Culley (Europe) or Clément Fortin (North America).